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Climate-Smart Agriculture in Highlands – Insights from Asia

AIT Asian Institute of Technology

NIPPON KOEI

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Knowledge Product

Climate-Smart Agriculture (CSA) in Highlands: Insights from Asia

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Preface

The International Workshop on Climate-Smart Agriculture (CSA) in Highlands, held on 29-30 October 2024 at the Asian Institute of Technology (AIT) Conference Centre, Pathum Thani, Thailand, brought together experts, policymakers, practitioners, and farmers to share experiences and insights on how CSA can improve agricultural competitiveness in highlands. The workshop facilitated discussions on practical advancements and knowledge-sharing to foster the adoption of CSA, addressing challenges through proven solutions, newly generated knowledge, and multi-sectoral, regional dialogues.

This knowledge product, titled "Climate-Smart Agriculture in Highlands: Insights from Asia," documents the key findings, case studies, and recommendations from the workshop. It aims to provide a comprehensive overview of the challenges and opportunities associated with p54romoting CSA in highland regions, drawing on insights from the Greater Mekong Subregion (GMS) and other countries.

The knowledge product is structured into six main sections:

(1) **Introduction:** Provides context and background information on CSA in highlands, highlighting the challenges and opportunities.
(2) **Climate Vulnerability and Adaptive Capacity Assessments:** Explores the vulnerability of highland agricultural systems to climate change and the adaptive capacity of communities and ecosystems.
(3) **Climate-Smart Agricultural Technologies and Practices:** Showcases innovative technologies and practices in water management, soil conservation, crop diversification, and other areas that can enhance the sustainability and resilience of highland agriculture.
(4) **Agricultural Product Quality, Value Chains, and Digital Technology:** Focuses on the importance of product quality, safety, and value addition in enhancing the competitiveness of highland agricultural products.
(5) **Knowledge and Capacity Enhancement on Climate Change Adaptation:** Emphasises the crucial role of knowledge and capacity building in empowering individuals, communities, and institutions to adapt to climate change and implement CSA practices effectively.
(6) **Conclusions and Recommendations:** Summarises the key findings and recommendations of the workshop, guiding future initiatives and investments to enhance CSA in the highlands.

We hope this knowledge product will be valuable for farmers, researchers, policymakers, and other stakeholders committed to promoting climate-smart agriculture in the highlands. Furthermore, it will provide practical insights, actionable strategies, and a collaborative framework for building more resilient and sustainable agricultural systems in these vital regions.

Contents

Preface i

Contents ii

Tables iv

Figures iv

Abbreviations vii

1. Introduction 1

1.1 Situation Context 1
1.2 Challenges for Climate-smart Agriculture in Highlands 1
1.3 International Workshop on Climate Smart Agriculture in Highlands: Best Practices and Lessons Learned 2

2. Climate Vulnerability and Adaptive Capacity Assessments 4

2.1 Case Study 1: Climate Change Projection, Impact Assessment, and Adaptation in Nan Highlands: A Top-Down Modelling Approach 5
2.2 Case Study 2: Climate Change Vulnerability of Agriculture Subsectors in Nan Province, and Capacity Needs and Gaps for Vulnerability Assessment 10
2.3 Case Study 3: Simple and Affordable Resilience Building Solutions for Mountain Agriculture 14
2.4 Case Study 4: Community-Led Climate Adaptation for Sustainable Farming: Experiences and Lessons Learned from Rural India 22
2.5 Case Study 5: Climate-Smart Farming in the Himalayas: Advancing Food Security and Livelihoods under changing Climate 19

3. Climate-Smart Agricultural Technologies and Practices 24

3.1 Case Study 6: Climate-Smart Water Management Practices in Nan 26
3.2 Case Study 7: Climate-Smart Soil Management 30
3.3 Case Study 8: Triple win of cassava-forage intercropping in highland agriculture: Soil fertility, cassava yield, and household income 38
3.4 Case Study 9: Capacity Enhancement of Himalayan Highland Communities through Development, Validation and popularization of Novel Multipurpose Pyrolizer cum Cooker for Climate Change Adaptation and Air Pollution Mitigation. 44
3.5 Case Study 10: Optimisation of Topography and Climate Conditions for Crop Diversification 46

4. Agricultural Product Quality, Value Chains and Digital Technology 50

4.1 Case Study 11: Agricultural Quality and Safety Improvement in Alternate Crops in Nan Province, Thailand 52
4.2 Case Study 12: Harnessing Digital Innovation to Elevate Food Safety and Quality: Insights from Thailand's Durian Export Industry 58
4.3 Case Study 13: Practical Digital Solutions for Smallholders: Linking Farm Management from Planting to Post-Harvest for Enhanced Traceability and Sustainability 65
4.4 Case Study 14: Enhancing Traceability and Authenticity of Sindhuli Junar through Blockchain Technology, Nepal 74

5. Knowledge and Capacity Enhancement on Climate Change Adaptation 78

5.1 Case Study 15: Enhancing Capacity of Local Government and Communities in Nan Province 80
5.2 Case Study 16: Building Climate Resilience through Climate Smart Agriculture in Nepal 84
5.3 Case Study 17: Enhancing Climate Change Adaptation Capacity of Smallholder Upland Farmers in Albay Province, Philippines through Rainwater Harvesting 90
5.4 Case Study 18: Restoring Ecosystems and Livelihoods: Agroecological Innovations in the Manupali Watershed, Mindanao, Philippines 94
5.5 Case Study 19: Alternate Wet & Dry Paddy Rice Planting increased yield and reduced emissions in Xundian County, Yunnan Province 99

6. Workshop Summary, Conclusions, Recommendations and the Way Forward 102

6.1 Experience Sharing on Pilot Demonstrations by Farmers in Bua Yai Subdistrict, Na Noi District, Nan Province 102
6.2 Climate-Smart Agriculture Investment Planning for Highlands 102
6.3 Summary 103
6.4 Conclusions 104
6.5 Recommendations 104
6.6 The Way Forward for Scaling Up CSA in Highlands 105

Tables

Table 1: Preferred new and alternative livelihood and production practices for addressing future climate change in the highlands of Thailand. 11

Table 2: Solar electricity generation of panels compared to the greenhouse gas emissions per unit of electricity produced. 27

Table 3: Geographical details of Buddhabhumi and Kageshwari. 84

Figures

Figure 1: Inauguration of the Capacity Building event on Climate Change Vulnerability Assessment in Highland Agriculture: Challenges and Opportunities held at Nan Province, Thailand. 7

Figure 2: Group Discussions at the Capacity Building event on Climate Change Vulnerability Assessment in Highland Agriculture: Challenges and Opportunities held at Nan Province, Thailand. 7

Figure 3: The Resilient Mountain Villages approach. 16

Figure 4: Effects of jholmal/no jholmal on rice yield (mean ±standard error) in 2016 in eight different sites: Patlekhet (PK),Kalchhebesi (KB), Nayagaun-Deupur (ND), Mahadevsthan Mandan (MM), Rabi (RB), Opi(OP), Baluwa (BA), and Bela(BE) (Source: Subedi et al., 2019). 17

Figure 5: Demonstration of simple, affordable and replicable solutions and technologies developed and managed by farmers at a local knowledge park. 18

Figure 6: Women group of one of the pilot villages in Nepal. 20

Figure 7: *Participatory modeling process*: Focus group discussion and group sketching and storytelling sessions to integrate farmers' perceptions and experiences within the co-design framework. 16

Figure 8: *Participatory Capacity-Building Workshop*: Farmers engage in a capacity-building workshop designed to deliver modelling findings and simulations. 16

Figure 10: Participatory implementation of co-designed early planting date. 1

Figure 9: Participatory implementation of early planting date. 1

Figure 11: Household data collection by project team. 20

Figure 12: Meetings with farmers and representatives of CBOs. 22

Figure 13: Training workshops on CSA for government officials in highlands. 22

Figure 14: The location of the solar irrigation and keyline ploughing pilot demonstration sites. 26

Figure 15: Solar Irrigation in Bua Yai. 29

Figure 16: Keyline Ploughing in Bua Yai. 29

Figure 17: A solar-powered pump at the Horticulture Innovation Lab's Regional Center at Kasetsart University, Thailand. 31

Figure 18: Solar-powered irrigation system, pump running on electricity generated by photovoltaic panels. 31

Figure 19: Biochar production process and its properties 32

Figure 20: Keyline plowing/subsoiling with Yeomans plow 32

Figure 21: Example of mulching practices. (A) Maise grown by adopting minimum tillage and mulching in Zambia; (B) Rice straw mulching in chili in Thailand. 33

Figure 22: Drought-tolerant hybrid maise at the Thai Department of Agriculture's Nakhon Sawan Field Crops Research Center. 33

Figure 23: Different types of agroforestry practices – (A) Coconut and turmeric agroforestry system in Tamil Nadu, India; (B) multilayered agroforestry practice with coconut-pineapple-millet; (C) Coconut and ginger agroforestry system in the Philippines; and (D) Keyline pattern cultivation under agroforestry system in the United States - Wisconsin. 34

Figure 24: Study site in Cau Vai village, Mau Dong commune, Van Yen district, Yen Bai province. 39

Figure 25: Recommendations for sharing accurate weather forecast information AND multi-level CSA cooperation for implementation of NTM's 2021-2030 strategy. 42

Figure 27: Microstructure of the biochar. 46

Figure 26: The pyrolyzer. 46

Figure 28: Nurseries in sand to make seedlings more dourght-tolerant. 48

Figure 29: Lower polytunnels, double tunnels, shade net tunnels, rain shelter tunnels, non-woven sheets and anti-hail nets were introduced for plant protection. 48

Figure 31: Completing questionnaires by meeting with farmers. 54

Figure 30: Completing questionnaires by meeting with farmers. 54

Figure 32: Engagement with Durian farmers. 61

Figure 33: The produce can be traced through an app. 62

Figure 34: QR codes on the trucks allowed real time monitoring during transport. 62

Figure 35: Utilizing various technologies to improve the visibility of farm and distillation operations. 66

Figure 36: Field polygon and farming activities of a Citronella farmer. 67

Figure 37: Customer point of view. A report on a specific batch (right) links its raw material to a specific farm (left). The two are linked by the Farm's ID. 67

Figure 38: Drone image collection by ListenField in collaboration with Kubota Research and Development Asia (KRDA). 68

Figure 39: Demonstrating traditional and modern soil nutrition assessment to farmers. 69

Figure 40: Training District Agricultural Extension Officers on web dashboards for farmer monitoring. 69

Figure 41: Training on mobile application for farm digitization on May 8, 2024. 70

Figure 42: Unlike drones, satellite image data can be continuously collected without traveling to the fields. 71

Figure 43: Daily precipitation was recorded for March to May 2024. Data from TMD stations overreported rainfall, which could affect decision-making. Precise microclimate readings are needed. 71

Figure 44: Sweet oranges grown in Sindhuli. 74

Figure 45: Training sessions conducted to educate farmers about blockchain technology, sustainable practices, and branding strategies. 76

Figure 46: Capacity-building events for farmers. 83

Figure 47: Engagement with government officials. 84

Figure 48: Vegetable farms in the semi-urban area (Kageshwari Manohara) and involvement of women farmers. 85

Figure 49: Women farmers participating in hands-on training session on Climate Smart Agriculture Practices (a) Drip Irrigation application, (b) Information charts and (c) Preparation of compost manure. 88

Figure 50: Co-establishment of rainwater harvesting facilities harnessing the collective action (bayanihan) of farmers in the three upland farming communities. 92

Figure 51: The type and size of rainwater harvesting ponds vary across the three project sites, depending on their local conditions. 92

Figure 52: Participatory mapping. 95

Figure 53: Laying out contour lines in demo farms in the MKRNP buffer zone using improvised A-frames. 97

Figure 54: Farmer planting native trees in alleys with vegetables. 97

Figure 55: Training farmers on RPQPT. 101

Figure 56: Weekly air sampling in collection boxes for methane content measurements. 101

Abbreviations

ADB	Asian Development Bank
AI	Artificial Intelligence
AIT	Asian Institute of Technology
APEC	Asia-Pacific Economic Cooperation
CASP	Core Agriculture Support Program
CBOs	Community-Based Organizations
CEAPRED	Centre of Environmental and Agricultural Policy Research, Extension and Development
CMIP6	Coupled Model Intercomparison Project Phase 6
CSA	Climate-Smart Agriculture
DSR	Direct-Seeded Rice
EPCIS	Electronic Product Code Information Services
FAO	Food and Agriculture Organization
GACC	General Administration of Customs China
GAP	Good Agricultural Practices
GB	Gilgit-Baltistan
GCMs	General Circulation Models
GESI	Gender Equality and Social Inclusion
GHG	Greenhouse Gas
GIS	Geographic Information Systems
GIZ	German Corporation for International Cooperation
GMP	Good Manufacturing Practices
GMS	Greater Mekong Subregion
GS1	Global Standards One (for traceability systems)
HACCP	Hazard Analysis and Critical Control Points
HACCP	Hazard Analysis and Critical Control Points
HKH	Hindu Kush Himalaya
ICIMOD	International Centre for Integrated Mountain Development
IDB	Inter-American Development Bank
IoT	Internet of Things
IPCC	Intergovernmental Panel on Climate Change
IPCC	Intergovernmental Panel on Climate Change

JICA	Japan International Cooperation
KR-20	Kuder-Richardson Formula 20
MARA	Ministry of Agriculture and Rural Affairs (China)
MOAC	Ministry of Agriculture and Cooperatives (Thailand)
NEM	Northeast Monsoon
NGO	Non-Governmental Organization
NGOs	Non-Governmental Organizations
NIR	Near Infrared
NSTDA	National Science and Technology Development Agency (Thailand)
PGS	Participatory Guarantee Systems
PPPs	Public-Private Partnerships
PRC	People's Republic of China
QR	Quick Response
R&D	Research and Development
RFID	Radio-Frequency Identification
RMS	Resilient Mountain Solutions
SASRP	Sustainable Agriculture and Food Security Program
SI	Supplemental Irrigation
SMEs	Small and Medium-sized Enterprises
SSP	Shared Socioeconomic Pathway
SWM	Southwest Monsoon
TA	Technical Assistance
TAS	Thai Agricultural Standard
TMD	Thai Meteorological Department
VA	Vulnerability Assessment
VI	Vulnerability Index
WGA	Working Group on Agriculture

1. Introduction

1.1 Situation Context

Agriculture is critical to Thailand's economy, as over 48% of the population lives in rural areas, and more than 30% of the workforce is employed in agriculture. However, the highlands of northern Thailand, particularly Nan Province, face significant challenges due to unsustainable farming practices, especially monoculture maise production. These practices have led to severe resource degradation, low crop productivity, and unstable incomes. The conversion of large tracts of forests into maise fields has resulted in deforestation, soil erosion, and landslides.

The excessive use of agrochemicals in maise cultivation has also led to the contamination of water sources, posing risks to both human health and aquatic ecosystems. The intensive use of synthetic fertilisers and pesticides, often promoted by government subsidies and private sector support, has disrupted natural ecosystems, reduced biodiversity, and increased soil erosion.

With rising temperatures and increased frequency of extreme weather events such as droughts and floods, climate change exacerbates these problems. The negative impacts of climate change on agricultural production and the livelihoods of rural communities in Thailand are a growing concern. The increasing variability and unpredictability of rainfall patterns are leading to more frequent droughts and floods, affecting water availability for irrigation, disrupting planting schedules, and increasing the risk of crop failure.

In addition to the environmental challenges, the highlands of northern Thailand face socioeconomic challenges, such as poverty, food insecurity, and land tenure issues. Many farmers lack secure land ownership or user rights, making investing in sustainable agricultural practices difficult. The lack of clear land titles and outdated forest regulations further complicate the situation.

These challenges highlight the urgent need for a transition to more sustainable agricultural practices in the highlands of northern Thailand. This transition should focus on promoting Climate-Smart Agriculture (CSA) and organic farming practices that can enhance the resilience of highland communities, protect the environment, and improve the sustainability of agricultural production.

1.2 Challenges for Climate-smart Agriculture in Highlands

In the uplands of Nan Province, unsustainable farming practices have presented challenges related to soil and water management. Culturing crops on sloping lands without adequate soil conservation measures has resulted in severe soil erosion, leading to topsoil and nutrient loss. Additionally, monoculture practices have led to soil degradation, characterised by low soil fertility and reduced crop yields. Overusing fertilisers and pesticides has also resulted in soil and water pollution, posing risks to human health and harming aquatic ecosystems. Another significant challenge in the uppermost reaches of the highlands is water scarcity, which limits alternative land use options and exacerbates drought conditions.

Land Tenure and Policy Challenges

In addition to the soil and water management challenges, CSA adoption in the highlands faces land tenure and policy-related challenges. Many farmers' lack of secure land ownership or user rights has hindered long-term investments in sustainable land management practices. Furthermore, the lack of supportive policies and incentives for CSA adoption has limited the transition to more sustainable agricultural practices.

Climate Change Impacts

Climate change significantly impacts agricultural practices in the highlands, primarily due to weather patterns' increasing variability and intensity. The erratic rainfall patterns affect water availability for irrigation, disrupt planting schedules, and increase the risk of crop failure. The rising temperatures affect crop growth and yields, especially for crops sensitive to heat stress.

Extreme weather events, such as droughts, floods, and heat waves, further compound the challenges. These events damage crops, livestock, and infrastructure, leading to food shortages, economic losses, and displacement of communities.

Socioeconomic Challenges

The highlands of Nan Province face socioeconomic challenges that can hinder the adoption of CSA practices. High poverty rates and income inequality limit farmers' access to resources, information, and technology, making investing in sustainable agricultural practices difficult.

The reliance on maise monoculture and vulnerability to climate change impacts contribute to food insecurity, affecting livelihoods and community well-being. Additionally, the remoteness of highland areas and lack of adequate infrastructure limit market access, making it challenging to sell produce at fair prices and access essential agricultural inputs.

1.3 International Workshop on Climate Smart Agriculture in Highlands: Best Practices and Lessons Learned

The International Workshop on Climate-Smart Agriculture in Highlands, held from 29-30 October 2024, brought together experts, policymakers, practitioners, and farmers to share experiences and insights on how CSA can improve highland agricultural competitiveness. The workshop facilitated discussions on practical advancements and knowledge-sharing to foster the adoption of CSA, addressing challenges through proven solutions, newly generated knowledge, and multi-sectoral, regional dialogues.

The workshop focused on three main objectives:

Focus on Highland Resilience

- Address unique risks: Discuss the specific challenges and vulnerabilities due to climate variability and extreme weather events in highland regions.
- Showcase success stories: Share case studies and pilot projects that demonstrate effective CSA techniques from highland areas.

Catalysing CSA Adoption

- Develop agri-food value chains: Explore new opportunities for enhancing value chains in highland agriculture, including digital technologies.
- Promote dialogue and partnerships: Encourage dialogue among stakeholders that drive the adoption of CSA practices and technologies in highland communities.

Building on Experience

- Leverage ADB TA-9993 and other project insights: Draw from the practical experience and lessons learned through implementing ADB TA-9993 and other projects to inspire future actions.

The workshop was organized around four key themes:

- Gender-Conscious Climate Vulnerability and Adaptive Capacity Assessments in Highlands
- Climate-Smart Agricultural Technologies and Practices for Highlands
- Agricultural Product Quality, Value Chains, and Digital Technology
- Knowledge and Capacity Enhancement of Local Governments and Highland Communities on Climate Change Adaptation

The workshop resulted in several key outputs:

- Practical insights and actionable strategies for promoting CSA in the highlands.
- A collaborative network of stakeholders committed to advancing CSA in the highlands.
- A set of recommendations and action plans that can guide future initiatives and investments to enhance CSA in the highlands.

2. Climate Vulnerability and Adaptive Capacity Assessments

This section explores the crucial process of evaluating how vulnerable various agricultural systems and communities are to the impacts of climate change through selected case studies. The effects of climate change vary from location to location, and the vulnerability of a place to climate change depends on the adaptive capacity of the place and people.

Vulnerability refers to the susceptibility of a system, such as a community or ecosystem, to the adverse effects of climate change. The impacts of climate change on a system depend on the system's exposure and sensitivity to climate change. Adaptive capacity is the ability of a system to adjust to climate change, moderate potential damages, take advantage of opportunities, or cope with the consequences. Vulnerability assessments are essential for several reasons: identifying vulnerable areas, guiding adaptation efforts, and evaluating progress. They help pinpoint locations, communities, or sectors particularly susceptible to climate change impacts. Vulnerability assessments inform adaptation planning and help prioritize adaptation measures for the most vulnerable areas. They provide a baseline for tracking the effectiveness of adaptation measures and monitoring changes in vulnerability over time.

Various methods can be used for vulnerability assessments, each with its strengths and limitations. Some standard techniques include surveys and interviews, geospatial analysis, crop modelling, and participatory approaches. These involve gathering qualitative data on farmers' and communities' perceptions of climate change impacts and their adaptive capacity; using GIS and remote sensing data to map and analyze vulnerability factors such as land use, soil type, and water resources; simulating the impacts of climate change on crop yields and water requirements using crop growth models; and engaging local communities in identifying and assessing their vulnerabilities and developing adaptation strategies, respectively.

Adaptive capacity is crucial in reducing vulnerability and enhancing resilience to climate change. Factors influencing adaptive capacity include access to resources, knowledge and skills, social capital, and governance and policies. These involve the availability of financial resources, technology, and infrastructure to support adaptation efforts; understanding climate change impacts and knowledge of effective adaptation strategies; strength of community networks and institutions to facilitate collective action and adaptation; and supportive policies and effective governance structures to enable adaptation planning and implementation, respectively. Vulnerability assessments and adaptation planning should be integrated to ensure that adaptation measures are targeted and effective. This involves identifying vulnerable hotspots, prioritizing adaptation measures, and developing locally appropriate adaptation strategies.

2.1 Case Study 1: Climate Change Projection, Impact Assessment, and Adaptation in Nan Highlands: A Top-Down Modelling Approach

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Abstract

The main aim of this study is to assess the current and future vulnerability of highland agriculture to climate change and recommend suitable adaptation practices to enhance the resilience of the system. Current study results show that the projected annual temperature will increase by 1.8 – 3.6 °C by the end of this century while the increase in minimum temperature is higher than that of maximum temperature. Projected rainfall shows a 4 – 37% increase with wide spatial variability across the Nan highlands in the future. Projected crop yields show increasing trends for Rice, Maize, and Soybean while a decreasing trend for Coffee crops. The Bua Yai district is the most vulnerable district to climate change in the future. This study has also identified the key driving factors causing high vulnerability and recommended suitable adaptation practices to improve sustainability in the highland agriculture in Nan province.

Background

Nan highlands is in the eastern part of northern Thailand sharing its border with Lao PDR in the eastern border. The elevation ranges from 200 m to 2000 m above mean sea level showing significant variations in the topography and abrupt changes in the weather patterns from low-lying areas to high mountains. Around 85% of the Nan province is mountainous terrain and only 2.5% of the total area comes under lowlands which makes limited access to crop cultivation in the province. The total population of Nan province is 478,000 of which 80% of the population is Northern Thai living in the lowland areas while the rest of the population belongs to five major ethnic minority groups namely Lau, Hmong, Mien, Khmu, and Mlabri. Agriculture-based income is the major source of income for the local people. Poverty and lack of land ownership are the major socio-economic problems of Nan people while the problems are also associated with environmental and unsustainable agricultural practices. For example, recent changes in agricultural practices such as monocropping with Maize and Rubber deplete specific soil nutrients and lead to reduced soil fertility and crop productivity. Moreover, highland slopes are prone to soil erosion when the soil is exposed between the planting seasons of monocropping. Lack of crop rotation also leads to reduced soil organic matter contents in the soil. Crops like maize require high water requirements which leads to overuse of water thus straining local water resources. Fertilizers and pesticides used in the monocropped fields lead to hazardous chemicals and contaminant runoff and pollution of nearby streams and rivers affecting downstream communities. In addition to these socio-economic and environmental related issues, climate change and climate variability also bring additional risks such as increasing temperature, floods, and droughts to the farming community in Nan highlands.

Rationale

Nan highlands in northern Thailand face critical environmental and socio-economic challenges due to various factors such as monocropping, extreme weather conditions, water scarcity, soil, and water pollution due to fertilizers and pesticides applications, soil erosion, reduced soil fertility and crop productivity, loss of biodiversity, lack of land ownership, low-income and poverty. The highlands are also sensitive to climate change and climate variability due to their steep slopes, thinner soils, and dependence on consistent rainfall and temperature conditions for sustainable agriculture. Any significant anomalies in the weather patterns directly threaten the highland ecosystems. The farming community and their livelihood in the Nan highlands mainly depend on agriculture and therefore they are more vulnerable to climate-induced disruptions like unpredictable weather patterns, droughts, floods, and increasing temperatures. Specifically, cash crops like coffee crops in Nan province are sensitive to climate anomalies and any significant increase in the temperature directly impacts the yield of the coffee crops and reduces the income of the farmers.

Assessing the current and future state of vulnerability of agricultural systems in Nan highlands is, therefore, critical for both identifying key drivers of highly vulnerable agricultural systems and as well as bringing suitable adaptation practices to minimize the negative impact of climate change on the highland agricultural practices in the highlands. Improving agricultural productivity and enhancing the resilience of agricultural systems to climate change can effectively be done by mapping the vulnerability of highland agricultural systems to climate change in the current and projected scenarios in the study area. Addressing and enhancing the resilience of highland agricultural systems to climate change is not only ensuring the sustainability of the local farming community in Nan highlands but also the ecological stability and food security of vulnerable and sensitive regions of highlands in Nan province.

Proposed Solution

The resilience of highland agriculture to climate change in Nan province can be enhanced by assessing the current and future state of vulnerability of agricultural systems to climate change and proposing suitable adaptation solutions in the identified critical areas. A case study has been conducted by considering 8 villages in the Bua Yai subdistrict of Na Noi district in Nan province. A vulnerability assessment framework was developed in which three major components, Exposure, Sensitivity, and Adaptive Capacity, were integrated to identify critically vulnerable regions in the study area (Naset et al., 2019). The exposure component indicates the degree to which a system is exposed to climate-related hazards. Here the system indicates 8 villages and their geographical locations including crop lands, livestock, and other agricultural-associated locations. Climate-related hazards indicate the duration and severity of extreme events such as floods and droughts. The sensitivity component indicates the extent to which the system is exposed or affected by climate-related hazards. For example, crop productivity, soil fertility, erosion, crop diversity, and population density are the sensitive parameters of a system, and assessing the impact of climate hazards on these parameters. Adaptive capacity indicates the ability of a system to adjust, adopt, and cope with the potential impacts of climate change (IPCC 2007a). Examples of adaptive capacity components include access to technology, knowledge and skills, land holding size, etc. The Vulnerability Index (VI) was calculated after normalizing and weighting the factors for the current (1985 – 2014) and future time periods (2020 – 2100).

This case study involves various stakeholders and agencies in collecting relevant datasets for the vulnerability assessment (VA) in the 8 selected villages of Bua Yai subdistricts in Nan province. Primary stakeholders include farmers from the region, government officials, policy makers, and students and scholars from research institutes and research organizations. Primary data was collected from the farmers directly through direct surveys while secondary data was collected from relevant public agencies in Thailand such as the Office of Agricultural Economics and, the Department of Agriculture Extension. In addition, global open-source datasets and datasets from literature were also used as alternate data where the information was not available or missing for conducting this study. For climate projection, six Coupled Model Intercomparison Project Phase 6 (CMIP6) General Circulation Models (GCMs) data were used to project the climate in the study area after correcting the bias with a quantile mapping-based bias correction process. For crop yield projection, the AquaCrop model was used to predict Maize, Soybean, Rice and Coffee crop yield with projected climate and other soil and crop-related datasets. The open-source R-programming platform was used to compile all indicator variables from Exposure, Sensitivity, and Adaptive Capacity components to calculate VI for the selected villages under different timescales and Shared Socioeconomic Pathway (SSP) scenarios.

The VA tool developed from this study was successfully demonstrated to the stakeholders through training and capacity-building workshops (Figures 1 and 2). Around 20 government officials from central, provincial, and local government bodies in Thailand along with farmers and other stakeholders were given step-by-step training on using this VA tool to project climate and assess the vulnerability of agricultural systems to climate change in the Nan province. The awareness among the farmers and stakeholders on the importance of using this VA tool to identify critical zones was conducted. Additionally, an analytical booklet on “Climate Change Vulnerability of Highland Agriculture: Insights from Nan Province” in both Thai and English language (KP2, 2021) and a guidance manual on “Guidelines for Vulnerability Assessment of Highland Agriculture” where this VA approach and methodologies have been discussed in detail (KP3, 2022).

Figure 1:
Inauguration of the Capacity Building event on Climate Change Vulnerability Assessment in Highland Agriculture: Challenges and Opportunities held at Nan Province, Thailand.

Figure 2:
Group Discussions at the Capacity Building event on Climate Change Vulnerability Assessment in Highland Agriculture: Challenges and Opportunities held at Nan Province, Thailand.

Lessons Learned

The projected climate in Nan province including Na Noi district and Bua Yai subdistrict shows that the minimum temperature will increase more than the maximum temperature by the end of this century. The minimum temperature is projected to increase by 3 – 4 °C while the maximum temperature is projected to increase from 2 – 3 °C from the baseline. Overall, the mean temperature is projected to increase by 1.8 – 3.6 °C by the end of this century. Projected rainfall on the other hand also shows the increased rainfall from the baseline period. The projected rainfall during annual, dry, and wet seasons analysis shows a 4 – 37 % increase in the rainfall while inconsistent patterns across the spatial and seasons scales were also observed.

Projected crop yield shows varying patterns across different crops. Soybean and maize crops show an increase in their yield by 1 – 33% by the end of this century while the projected rice yield during the mid and far future shows a 2 – 15% increase while it shows a decrease in the yield by 1 – 5% during near future. The coffee crop shows a consistent decrease in the yield of 14 – 32%. This decrease in the coffee yield could be attributed to the fact that the projected temperature is increasing as coffee crops are sensitive to elevated temperatures.

VA shows that out of 8 villages in the Bua Yai subdistrict, B. Mai Mongkol and B. Tabman villages were very highly vulnerable to climate change in mid future (2047 – 2073) under SSP2-4.5 scenario while all 8 villages show very high vulnerability in far future (2074 – 2100) under SSP585 scenario.

This study also identified four key driving factors, annual rainfall, crop water use efficiency, soil organic matter in the topsoil, and soil acidity, that link to significant changes in the vulnerability of agricultural systems to climate change.

Recommendations

Recommended adaptation practices to reduce the impact of climate change in Nan province for water management include the development of alternative irrigation facilities where on-farm reservoirs and rainwater harvesting can be implemented as change in annual rainfall was identified as one of the driving factors to vulnerable agricultural systems. Recommended adaptations for crop management include shifting to water-efficient crops, cover crops, and mulching practices as crop water use efficiency is being identified as one of the critical factors. For soil management, the recommended adaptations include the addition of biochar and compost to increase organic matter content in the soil and crop rotation to improve soil structure and nutrient availability. For acidic soils, the recommended adaptations include liming of soils, mulching to neutralize soil pH gradually over time, and the selection of suitable crops based on soil pH.

It is also recommended to have capacity-building programs from academic and government institutions for the farmers and stakeholders in the study area on climate change vulnerability and its impact in the agricultural sector for enhanced knowledge and adequate actions on adaptation practices. Policy interventions for these recommended adaptation practices include a field-based demonstration of these practices to the farmers and showing their benefits, through technical assistance where farmers are exposed to advanced technology, knowledge, and skill to manage their farms productively, and through extension services where farmers get up-to-date knowledge and support from the extension departments and institution.

Further Reading

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2.2 Case Study 2: Climate Change Vulnerability of Agriculture Subsectors in Nan Province, and Capacity Needs and Gaps for Vulnerability Assessment

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Abstract

Highland communities are facing numerous challenges that heighten their susceptibility to climate change, particularly because of rapid alterations in land use and land cover, which in turn affect local ecosystems. In the absence of non-governmental organizations and other non-state entities, local governments assume a crucial role in enhancing community resilience. It is vital to equip these local authorities with enough resources, well-defined mandates, and comprehensive strategic plans to shift from a reactive to a proactive approach in tackling future challenges. Emphasizing the empowerment of local communities and governments is essential, alongside the cultivation of a network of local stakeholders. This network should include non-governmental organizations, strong collaborations with the private sector, and the collaborative development of a highland adaptation agenda, with research and educational institutions serving as the focal point of the strategy for enhancing resilience in highland areas.

Background (200 words)

The Thai highlands are currently facing significant pressures. This mountainous area includes nine administrative provinces in northern Thailand. Key agricultural challenges in the Thai highlands encompass severe soil degradation, erosion, environmental chemical contamination, and the impacts of climate change. Rapid transformations in agricultural practices and socio-economic conditions are occurring, which may threaten the sustainability of the highland ecosystems. A notable shift in land use has been the expansion of rubber plantations, supported by government initiatives since the 1970s, alongside the increase in maize cultivation driven by the global demand for commercial feedstocks. These developments have led to considerable environmental degradation and the destruction of natural habitats. Over time, these rapid land use changes have significantly contributed to deforestation and various environmental issues in the region. Unsustainable agricultural practices and the over-exploitation of natural resources have resulted in severe natural resource depletion, diminished productivity, declining community and animal health, and unstable income levels. Between 2002 and 2023, approximately 372,640 hectares of humid primary forest were lost in the highland provinces (Global Forest Watch, 2023). The deforested areas have been converted into rubber plantations, maize monocultures, and, in some instances, rainfed paddy fields. These alterations in land use are adversely affecting biodiversity, land cover, soil health, and overall environmental quality in the highlands.

The highlands are particularly susceptible to the risks associated with climate change. The aforementioned factors render these ecosystems among the most vulnerable to climate change impacts. Given their remoteness and the limited economic development experienced over the years, these regions are anticipated to face significant consequences from climate change, exacerbated by their high vulnerability and sensitivity, as well as the disproportionate warming projected for these areas.

Rationale

Consultations conducted with experts and community stakeholders conducted for the design of the ADB project (TA9993) revealed that highland regions are particularly susceptible to the impacts of climate change and lack the necessary capacity to evaluate their vulnerability and implement appropriate mitigation strategies. This deficiency is primarily attributed to insufficient data, a shortage of both technical and administrative human resources, and inadequate financial resources to support targeted initiatives aimed at addressing these vulnerabilities. Additionally, the slow and limited attention from governmental bodies towards these susceptible ecosystems, which have only recently been recognized as economic assets, further hampers development in vulnerability assessments.

The significant spatial variability in the characteristics of highland areas necessitates the collection of high-resolution and high-quality data regarding both biophysical and socio-economic conditions, which is largely absent in these regions. There is a scarcity of both homogeneous and disaggregated data across most highland areas, compelling researchers to rely on assumptions that complicate the analysis and interpretation of local conditions. Most existing vulnerability research tends to concentrate on lowland areas. Vulnerability indicators are often specific to locations, making it difficult to apply findings from other regions directly to highland contexts. Furthermore, as vulnerability studies frequently focus on hazard-specific scenarios, the distinct nature and intensity of hazards in highlands compared to lowlands limit the applicability and relevance of existing research to highland conditions.

Proposed Solution

The Thai highlands, despite their numerous vulnerability factors, present a distinctive opportunity to explore various aspects of vulnerability that may not be as readily accessible in other regions. The highlands' significant reliance on natural resources for social resilience, along with the critical roles played by biodiversity and ecosystem services, offers valuable insights into the management of these resources. Evidence indicates that animal husbandry is vital for enhancing resilience in highland areas, highlighting the necessity to promote practices to foster resource circularity and develop closed-loop agricultural systems that can bolster agricultural resilience. Additionally, the highlands facilitate greater crop diversification opportunities because of vertical warming. Traditional agricultural practices, which have developed in harmony with local ecosystems and cultural traditions, contribute to the conservation of these ecosystems. Various strategies have been identified through participatory approaches, including focus group discussions and individual consultations with farmers, local authorities, and NGOs (see Table 1).

Table 1:
Preferred new and alternative livelihood and production practices for addressing future climate change in the highlands of Thailand.

Category	Options
Agriculture	Climate-controlled storage facilities
	Drought and low-temperature tolerant crop varieties
	Forest fire forecasting
	Effective dissemination of weather information and guidance on usage
	Crop insurance
	New and improved integrated pest and disease management methods
	Expansion of irrigation facilities including solar irrigation
	New and alternative crops suitable for future climate change
	Capacity building on low input and organic farming methods
	Support services including market price forecasting and market linkage development
	Farm financial management strategies
Animal husbandry	Disease management through vaccinations

Category	Options
	Improved breeds
	Measures to mitigate GHG gas emissions in animal husbandry
	Commercial methods of growing animal husbandry
	Market linkages, branding, and value addition
Plantations	Effective use of vertical space of plantations
	Improved plantation management for climate change resilience and GHG mitigation
	Address slope stabilization and soil erosion issues
	Supply chain management and access to better markets and prices

The proposed solutions can only be effectively executed if appropriate governance frameworks are established to enhance the capabilities of local governments and non-governmental organizations (NGOs) in their interactions with local communities. Key governance strategies include: 1. Granting sufficient financial independence to local governments, enabling them to make informed decisions regarding budget allocations; 2. Ensuring the availability of adequate technical expertise in critical areas such as agriculture and rural development, allowing local governments to implement community-relevant projects; 3. Fostering the development of NGOs and other organizations through regular collaboration and engagement; 4. Empowering local governments with a strengthened mandate to proactively design and execute initiatives addressing climate change and vulnerability mitigation; and 5. Enhancing local market structures and establishing connections with external markets to serve as catalysts for diversifying local livelihoods, improving skills, and increasing the capacity to produce high-quality goods and services.

Lessons Learned

Three significant lessons emerged from the exploration of vulnerabilities in the Thai highlands. These lessons are as follows:

(1) An excessive focus on gender-related vulnerability assessments may lead to the pursuit of non-existent issues. The communities in the Thai highlands exhibit higher degrees of gender equality, to for example Indian and African rural communities, making the concept of gender disparity difficult for them to comprehend. Consequently, it is crucial to avoid imposing global perspectives or irrelevant conceptual frameworks when conducting these assessments. Addressing gender-related concerns necessitates a nuanced understanding and a careful evaluation of the methodologies and assumptions applied in these contexts.

(2) The foundation of vulnerability reduction lies in the enhancement of local government capacities. The communities in the highlands are characterized by their entrepreneurial spirit and a continuous quest for improved livelihoods. They are already engaged in producing high-quality agricultural products and are eager to adopt innovative technologies. Despite these attributes, local governments struggle to connect with these communities and deliver essential extension and support services. Both local communities and NGOs perceive local governments as lacking in technical and financial capabilities. Therefore, it is imperative to prioritize the strengthening of local government capacities before focusing on the development of local community capacities.

(3) Effective multi-stakeholder collaboration is essential for bolstering the capacities of both local governments and communities. As previously noted, the independent nature of local governments hampers their ability to engage with local communities and NGOs. Furthermore, the tendency for government departments to operate in silos, coupled with a lack of inter-departmental cooperation, poses challenges to the implementation of integrated, whole-of-government strategies.

Recommendations

The lack of both quantitative and qualitative vulnerability assessments in highland regions represents a significant barrier to enhancing their resilience. It is essential for highlands to possess location-specific data to facilitate informed and effective decision-making. The pronounced spatial variability in the local characteristics of highlands necessitates the acquisition of high-resolution, granular data encompassing all biophysical and socio-economic factors. Addressing this requirement will demand considerable investment in data collection, archiving, and analysis, which should inform policy decisions across various governance levels. Such initiatives should aim to produce both homogeneous and disaggregated datasets pertinent to highland areas.

Furthermore, it is crucial for researchers and institutional stakeholders, including academic institutions, to devise suitable analytical methods and interpretative frameworks that yield location-specific solutions. There is a pressing need for vulnerability indicators tailored to the unique conditions of highlands, minimizing dependence on data from other regions for decision-making. Additionally, given that vulnerability assessments often concentrate on hazard-specific scenarios, the distinct nature and intensity of hazards in highlands compared to lowlands can limit the applicability and relevance of lowland findings to highland contexts. Even within highland regions, the challenge of spatial extrapolation of vulnerabilities is exacerbated by significant vertical and horizontal heterogeneity.

2.3 Case Study 3: Simple and Affordable Resilience Building Solutions for Mountain Agriculture

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Abstract

The Hindu Kush Himalaya (HKH) region is home to over 240 million people and supports 1.65 billion downstream dependents. This fragile mountain ecosystem faces severe climate challenges, including rising temperatures, erratic rainfall, and extreme weather, which jeopardize livelihoods, agriculture, and food security. Smallholder farming communities in areas like the mid-hills of Nepal, India (Uttarakhand), Myanmar, and Bhutan's highlands exemplify these struggles, grappling with declining soil fertility, water scarcity, and the disproportionate burden on women due to high male outmigration.

To build resilience, mountain-specific solutions that integrate traditional knowledge with scientific innovations are critical. Across several villages in Nepal and Bhutan, simple and affordable solutions such as biofertilizers, climate-smart agricultural practices, water conservation, and digital tools for weather and market information have shown promise. These initiatives enhance productivity and community resilience while minimizing environmental harm. Scaling such solutions requires context-specific strategies, partnerships, and alignment with policies, offering valuable lessons for strengthening resilience across mountain ecosystems globally. This case study highlights the interventions and outcomes of the Resilient Mountain Solutions initiative, led by the International Centre for Integrated Mountain Development (ICIMOD), mainly focusing on results from Nepal but also drawing lessons from Bhutan, India, and Myanmar, therefore, offering valuable insights into fostering climate resilience in diverse and fragile mountain ecosystems.

Background

The Hindu Kush Himalaya (HKH) region spans 3,500 km across eight countries from Myanmar to Afghanistan and supports 240 million residents and an additional 1.65 billion downstream dependents. This region is disproportionately impacted by climate change and rapid economic development, with projections indicating a temperature rise of 1–2°C by 2050, erratic monsoons, and intense but infrequent rainfall. Such changes exacerbate the vulnerability of mountain communities to flash floods, prolonged droughts, and variable river flows, designating the HKH as a "climate change hotspot." These environmental challenges threaten livelihoods, particularly in agriculture-reliant communities where the sector forms the socio-economic backbone.

The mid-hills of Nepal exemplify these challenges. Elevation varies from 700 meters to 1,600 meters and supports diverse climatic conditions ranging from subtropical to temperate. Approximately 70% of the population relies on agriculture, producing essential foods like fresh vegetables, rice, and fruits, and is dominated by smallholder farming integrated with forestry and livestock. Smallholders, who on average hold less than 1 hectare of land, face compounding challenges of declining soil fertility, pest infestations, and increasing water scarcity.

The mid-hills of Nepal also experience high outmigration, with 38.6% of households having at least one emigrant. This reduces the local workforce, leaving women to manage agriculture and natural resources. Despite their critical roles, women lack decision-making representation and access to tools, knowledge, and services, further exacerbating vulnerabilities.

In Nepal, the Resilient Mountain Solutions (RMS) (Figure 3) approach was piloted in two districts – Kavre and Dadeldhura. Vulnerability assessments highlighted key risks, including droughts, pest attacks, declining soil fertility, and lack of technical knowledge. Addressing these interconnected challenges was crucial to sustaining livelihoods, empowering marginalized groups, and building resilience against escalating climate uncertainties.

Rationale

Apart from general socioeconomic and climatic challenges, mountain communities face another set of challenges such as fragility, marginality, and limited accessibility. Generic agricultural models often fail in these contexts. Given the sensitivity of mountain farms, agricultural diversification and opportunities for mountain niche products are more effective than land-intensive technologies. Climate-resilient solutions should therefore focus on simple and affordable technologies that are easy for communities to adopt and integrate into their existing practices.

The RMS approach addressed these challenges by implementing context-specific, affordable, and adaptable solutions to help communities cope with unpredictable climate patterns. Aligned with the Climate-Smart Agriculture (CSA) framework, RMS integrates scientific knowledge with traditional practices to increase productivity sustainably and build resilience to climate change.

Resilience-building reflects societal values, determining what to preserve or change. In mountain regions, where diversity and variability are significant, flexibility is essential in resilience-building strategies. These must be participatory, locally determined, and adaptable to the specific needs and contexts of each community.

RMS approaches for resilience building use three key goals:

(1) **Climate Resilience:** Focuses on enhancing farming systems, improving water management, promoting renewable energy for productive uses, and improving soil fertility to adapt to climate change. It emphasizes flexible, diversified, and climate-friendly approaches that can be easily adopted by farmers.

(2) **Socioeconomic Resilience**: Aims to strengthen community resilience by promoting sustainable economic development, creating social safety nets, supporting marginalized groups (especially women), and enhancing local decision-making capacities. It ensures that socio-political factors are addressed alongside technical interventions to reduce vulnerability.

(3) **Future Resilience:** Focuses on equipping communities with the necessary resources, skills, and financial security to adapt to unforeseen risks and disasters. It emphasizes access to timely information, financial mechanisms like insurance, and the development of disaster preparedness plans, fostering a two-way communication link between communities and local governments.

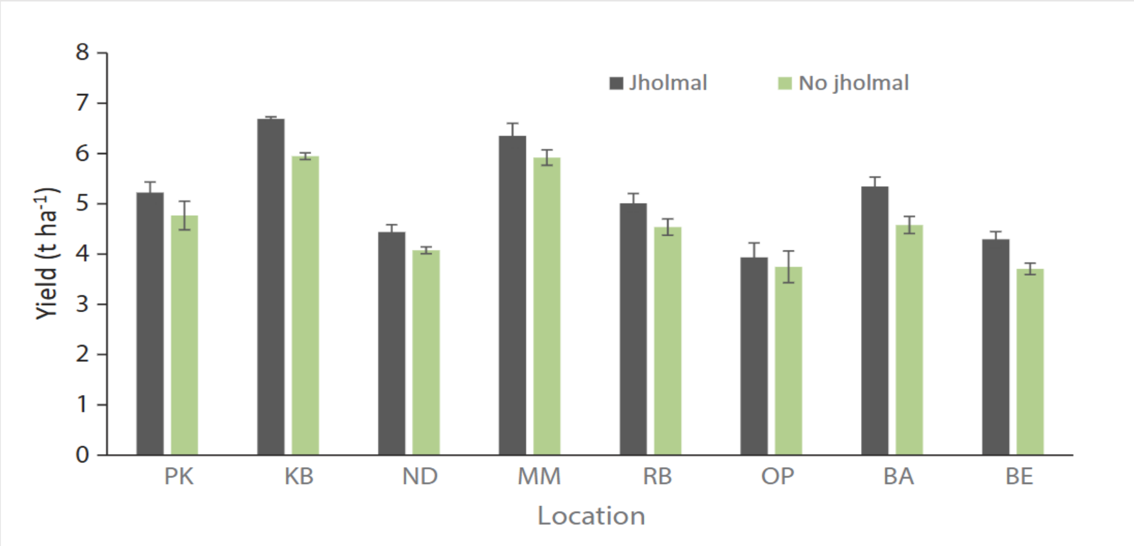
Figure 3:
The Resilient Mountain Villages approach.

Proposed Solutions

Climate-smart practices or technologies implemented:

(1) **Use of Jholmal:** Farmers are encouraged to adopt *Jholmal*, a liquid biofertilizer, and biopesticide, which is made from cattle urine and locally available plants. *Jholmal* has properties to repel kill insects and reduce pest infestation promoting increases in crop yields and reduced pest infestation (Subedi et al., 2019; Bhusal et al., 2022; Tashi et al., 2023). It reduces dependency on chemical inputs, improves soil health, and enhances plant resistance to diseases (Figure 4). Awareness campaigns and demonstrations have increased the uptake of *Jholmal*, and local agro-veterinary shops report reduced demand for chemical fertilizers. Additionally, the farmers' tendency to increasingly use green and farmyard manure, along with crop residue and mulching effectively improved soil quality and soil water retention.

Figure 4:
Effects of jholmal/no jholmal on rice yield (mean ±standard error) in 2016 in eight different sites: Patlekhet (PK),Kalchhebesi (KB), Nayagaun-Deupur (ND), Mahadevsthan Mandan (MM), Rabi (RB), Opi(OP), Baluwa (BA), and Bela(BE) (Source: Subedi et al., 2019).



(2) **Efficient Farming Practices**: Techniques like direct-seeded rice (DSR) improve yields, save water, and reduce labour. Polyhouses facilitate off-season vegetable production, addressing food security and market demand.

(3) **Solar Energy**: Solar-powered irrigation pumps are demonstrated to encourage the shift to renewable energy for irrigation.

(4) **Digital Services and Weather Data**: Mobile-based agricultural advisories deliver timely information to over 1,000 farmers on weather, market prices, and technical practices. Five schools were equipped with meteorological stations to generate local weather data and educate students about climate change.

(5) **Water Conservation Initiatives:** Effective water conservation practices such as soil-cement tanks, drip irrigation, and roof water harvesting led to better irrigation enhancing agricultural production.

(6) **Community Knowledge Park:** Demonstration of these simple and affordable solutions at one place at the community level provided a platform for learning and sharing for wider uptake and replication of these solutions by other farmers.

Figure 5:
Demonstration of simple, affordable and replicable solutions and technologies developed and managed by farmers at a local knowledge park.

Apart from the abovementioned practices, RMS also focused on empowering women farmers by training them in sustainable practices and engaging them in village-level planning and decision-making (Figure 5). Some new farmers' groups were established to enable social safety nets for collective decision-making, information sharing, and community-driven campaigns.

Innovations and their relevance in the highlands:

(1) The innovations implemented by the RMS approach address the challenges faced by mountain farmers in a holistic way. For example, solutions such as Jholmal are especially suitable to support organic farming practices by reducing dependency on chemical fertilizers. In one of the two districts where the excessive use of chemical pesticides had raised concerns about the quality of vegetables, the use of Jholmal as biofertilizers and pesticides not only reduced the input costs of the farmers but also enhanced consumers' trust in marketed local products such as fresh organic vegetables.
(2) Additionally, remote highland communities face connectivity issues, limiting access to information and services. To tackle this, mobile-based agricultural advisories were introduced, providing over 1,000 farmers with timely weather updates, market prices, and technical guidance. Meteorological stations set up in five schools further supported local weather data collection and climate change education.
(3) Unique social challenges, such as high outmigration, limited access to resources, and restricted decision-making power for women, were addressed. Solutions were kept simple and affordable to ensure high adoption rate among women farmers.

Role of Stakeholders:

(1) **Community:** In the RMS approach, community members are active participants who integrate traditional knowledge with scientific methods. They play a crucial role in adopting natural and resource-efficient practices which result in increased yields, cost savings, improved resilience, and reduced health risks from chemicals. Their willingness to adapt to changing circumstances is essential for the success of the model.
(2) **Municipal Government:** The local municipality provided not only partial financing for infrastructure such as polyhouses and water storage ponds but also actively engaged with other actors like digital services providers, the private sector, and other municipalities for learning, sharing, and up-scaling. They also facilitated market access for organic and off-season produce and contributed to disaster preparedness for farmers, enhancing resilience.

(3) **Government:** The government plays a non-negotiable role in the RMS approach. Working closely with local governments to enhance ownership and engagement and with the federal government to institutionalize and scale up the model has been the most important factor in the success of the RMS approach. The approach has now been upscaled with budget allocations for 41 municipalities across Nepal.

(4) **Non-Governmental Organizations (NGOs):** NGOs provide technical support and promote community engagement through the establishment of farmers' groups, gender inclusion, and participatory decision-making. Organizations like the Centre of Environmental and Agricultural Policy Research, Extension and Development (CEAPRED) worked with ICIMOD from the beginning to implement RMS and secured additional funding to expand the approach, with a focus on building adaptive capacity and climate resilience in multiple districts of Nepal.

Lessons Learned

Productivity Gains:

(1) The use of Jholmal has shown remarkable results in increasing crop yields. On-farm experiments conducted during 2014–16 and later revealed a statistically significant increase ($p<0.01$) in rice yields when using Jholmal compared to traditional chemical fertilizers and pesticides.

(2) Additionally, low-cost soil-cement ponds for water storage simplified crop irrigation, leading to time-saving by farmers. These combined efforts have enhanced savings and productivity.

Resilience building:

(1) **Addressing Water Scarcity and Uncertainty**: Soil-cement ponds and rooftop rainwater harvesting for collecting wastewater and rainwater proved useful for irrigation and livestock use. Improved water availability led to increased vegetable production and reduced vulnerability to water scarcity.

(2) **Environmental Benefits:** Practices such as crop rotation, mixed cropping, and intercropping helped maintain soil fertility and moisture. Testing crop varieties for suitability to local rainfall patterns and climate conditions enabled farmers to make informed, resilient choices. Techniques like home gardening, integrated pest management, and using *Jholmal* instead of chemical inputs mitigated environmental harm while increasing yields and preserving soil and human health.

(3) **Economic and Social Empowerment:** RMS successfully mobilized farmers into groups, with over 80% participation by women, fostering shared learning, collective action, and decision-making. These groups strengthen institutional frameworks by collaborating with local governments to ensure ownership and long-term sustainability.

(4) **Women's leadership:** With male out-migration leaving women to manage agriculture and natural resources, RMS's focus on equipping women farmers with knowledge and tools to adapt to climatic and socioeconomic changes proved helpful. Training on low-cost, simple, and sustainable practices enhances their leadership and decision-making power. By linking women's groups with local authorities, RMS facilitated their active participation in village-level planning and resource management (Figure 6).

Figure 6:
Women group of one of the pilot villages in Nepal.

Challenges and Barriers:

While the RMS approach proved beneficial, certain challenges must be considered to ensure effective implementation:

(1) **Context-Specific Solutions:** The approach emphasizes site-specific solutions based on vulnerability assessments. This makes up-scaling challenging, as technologies and policies must be tailored for each location, with no universal blueprint for practices.
(2) **Risk Aversion Among Subsistence Farmers:** Most farmers in mountain regions are smallholder subsistence farmers who cannot afford to take risks with new technologies. If an innovative practice fails, it can significantly increase their vulnerability, making adoption difficult. Additionally, the limited market for organic products reduces the economic viability of transitioning to sustainable practices.
(3) **Community Engagement:** Effective community engagement is vital to onboard farmers and stakeholders, but it is a time-intensive process.
(4) **Global Socioeconomic Trends:** Migration from mountain regions reduces the availability of labour, increasing labour costs and placing additional burdens on those left behind, especially women farmers. This dynamic complicates efforts to implement labour-intensive practices.
(5) **Stakeholder Collaboration:** The RMS project benefits from the support of various local institutions, aligning with the system's approach and broadening ownership. However, involving multiple stakeholders can dilute accountability, and effective coordination across diverse actors can be challenging.

Recommendations

Strategies to Enhance CSA Adoption:

(1) **Simple and Affordable**: Ensure proposed solutions are easy to implement, affordable, and inclusive of all.
(2) **Adaptable**: Customize solutions and approaches/strategies to local contexts and needs.
(3) **NGO Partnerships**: Collaborate with new NGOs to explore similar regions and communities.
(4) **Knowledge Sharing**: Promote co-production and transfer of knowledge for wider replication and scaling of effective practices like *Jholmal* and soil-cement tanks.

Suggestions for Policymakers, Researchers, and Practitioners:

(1) **Early Engagements with Local Governments**: Ensure local ownership by involving municipalities and provinces from the start of planning and conceptualization of ideas.
(2) **Align with Policy Priorities**: Position the project as a solution that addresses national and global policy needs.
(3) **Increase Investments**: Secure targeted funding for up-scaling and long-term sustainability.
(4) **Generate Science-based Evidence**: It is critical to generate evidence of the effectiveness of the solutions in the local context for the purpose of scaling.
(5) **Capacity Building**: Capacity building for the local community as well as other stakeholders on the application and extension of solutions.
(6) **Collaboration**: Use collaborative approaches for up-scaling and promoting investment.

Incentives for Private Sector Involvement:

(1) **Integrate Private Sector Products**: Use sustainable private sector products such as renewable energy, digital services, and market linkages in the initial setup to ensure long-term self-sufficiency.
(2) **Support Local Entrepreneurship**: Encourage local businesses based on traditional knowledge, mountain-niche products as well as eco-tourism while ensuring environmental sustainability and community benefits.

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2.4 Case Study 4: Community-Led Climate Adaptation for Sustainable Farming: Experiences and Lessons Learned from Rural India

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Abstract

With climate change intensifying rainfall variability across South Asia, implementing climate adaptation measures is vital to mitigate its adverse effects on agriculture in India's semi-arid tropics. This study aimed to develop sustainable strategies to address climate change-induced challenges to crop productivity through a participatory modelling approach. Using the AquaCrop model, an interactive modelling process was integrated into a co-design framework to incorporate stakeholder perceptions, experiences, and inputs gathered through interviews and discussions. We then evaluated the effectiveness of identified solutions, including optimized sowing windows, crop switching, and supplemental irrigation (SI), in mitigating water stress. Historical and future yield simulations demonstrated that early sowing significantly reduces water demand while boosting yields. Crop-switching assessments revealed that replacing maize and rice with sorghum reduced SI requirements by up to 90%. These adaptive strategies emphasize the critical role of climate-resilient practices in ensuring sustainable food production, conserving water resources, and safeguarding farmer livelihoods amidst growing climate uncertainties.

Background

The study was conducted in the foothills of the Western Ghats, specifically in the Thondamuthur block of Tamil Nadu, India. The region lies within the semi-arid tropics, characterized by a mean annual rainfall of 590 mm and an average annual temperature of 26.5°C. The Thondamuthur block spans a geographical area of approximately 480 sq. km, located between 10°54′42.57″ N, 76°41′14.46″ E and 11°1′20.33″ N, 76°55′12.4″ E. The region's topography is marked by undulating terrain with predominantly clay loam soils, known for their moderate water retention capacity and adaptability to arid conditions when supplemented with organic matter. Agriculture is the backbone of the Thondamuthur block, accounting for 48% of the land use and serving as the primary livelihood for most of the population. Key crops include rice, maize, and sorghum, which are cultivated under rainfed conditions, making the sector highly dependent on monsoon rains. Rice farming occurs during two main growing seasons: Kharif (May–September), coinciding with the Southwest Monsoon (SWM), and Rabi (October–February), relying on Northeast Monsoon (NEM) rainfall. Farmers in the region face challenges such as water scarcity due to groundwater depletion and irregular rainfall patterns. Limited access to technological advancements, financial resources, and market opportunities further constrain productivity. The region experiences extreme rainfall variability, which exacerbates risks such as drought, soil degradation, and crop yield anomalies. These challenges undermine agricultural sustainability and heighten the vulnerability to climate change impacts. Prolonged dry spells, coupled with declining soil quality and erosion, further diminish the resilience of agricultural systems. Addressing these challenges requires the adoption of adaptive practices such as optimized sowing dates and supplemental irrigation (SI). These measures aim to mitigate water stress, enhance crop productivity, and secure livelihoods in this semi-arid region.

Rationale

This study addresses three pillars of Climate-Smart Agriculture (CSA), focusing on increasing agricultural productivity sustainably, enhancing resilience to climate change, and reducing greenhouse gas emissions where possible. Small-scale farming in the Thondamuthur block of Tamil Nadu faces significant challenges from climate-induced variability. The study developed community-based climate adaptation measures to enhance agricultural productivity while conserving natural resources. Strategies such as optimal sowing dates and supplemental irrigation

(SI) schedules were co-designed with local farmers to align with monsoon variability (Abed et al., 2025). These proactive approaches optimize resource use and maintain productivity even in adverse conditions, ensuring long-term agricultural sustainability. The research employed a participatory framework that integrated farmers' perspectives with technical analyses, including rainfall variability assessments and crop modelling (Barati et al., 2022). By adjusting the sowing window to align with projected rainfall patterns and designing rational SI schedules, the study mitigated water stress risks and reduced vulnerability to erratic rainfall. Substituting crops such as Rabi sorghum for water-intensive rice and maize further decreased seasonal water requirements by up to 90%. These measures empower farmers to adapt their practices to climate uncertainties, enhancing the resilience of small-scale farming systems against future climate variability. The study also explored crop diversification and water management strategies to reduce greenhouse gas emissions (Barati et al., 2024). While solar pumps have a minimal carbon footprint, deep groundwater extraction depends on diesel pumps, as solar alternatives are impractical due to cost and technical constraints, contributing to CO_2 emissions. To address this, shifting to less water-intensive crops and adjusting crop calendar to rainfall can reduce diesel usages, lowering emissions. Optimized sowing dates and improved rainfall use further minimize groundwater extraction. As a result, community-based adaptation strategies promote practices that align with low-carbon agricultural strategies.

Proposed Solution

The study implemented tailored climate-smart practices to address the unique challenges of the semi-arid, highland context in the Thondamuthur block. Key measures included adjusting sowing dates to align with shifting rainfall patterns, designing efficient supplemental irrigation (SI) schedules based on rainfall variability, and promoting crop diversification toward less water-intensive crops like sorghum. These innovations developed through a participatory co-design framework ensured that solutions were practical and aligned with the needs and adaptive capacities of local farmers. Advanced tools, such as AquaCrop modelling and CMIP6 climate projections, were integrated to predict future climate impacts, enabling precise adaptation strategies. By optimizing water use, enhancing yields, and building resilience to climate variability, these practices not only improved agricultural sustainability but also addressed resource constraints critical in highland farming systems.

The success of these practices was underpinned by collaboration among key stakeholders. Farmers were actively involved in co-creating and adopting these solutions, with perceived benefits like reduced water stress and improved productivity driving adoption rates despite challenges such as limited financial resources (Figure 7 and Figure 8). The private sector supported the initiative by providing irrigation equipment, soil amendments, and market linkages, while government subsidies for irrigation infrastructure and policies promoting rainwater harvesting and crop diversification further strengthened implementation. Non-governmental organizations (NGOs) played a crucial role in community engagement and technical support, ensuring solutions were culturally and socio-economically appropriate. This collaborative approach demonstrates a scalable model for climate adaptation in highland regions, offering actionable insights into enhancing agricultural productivity, resilience, and sustainability in the face of climate change.

Figure 7:
Participatory modeling process: Focus group discussion and group sketching and storytelling sessions to integrate farmers' perceptions and experiences within the co-design framework.

Figure 8:
Participatory Capacity-Building Workshop: Farmers engage in a capacity-building workshop designed to deliver modelling findings and simulations.

Lessons Learned

The implementation of climate-smart practices in the Thondamuthur block yielded significant productivity gains. Adjusting sowing dates and adopting supplemental irrigation schedules increased yields for key crops, with early-sown Rabi rice and maize achieving yield improvements of 88% and 12%, respectively (Barati et al., 2024). These practices not only enhanced crop productivity but also improved farmers' incomes, contributing to better livelihood security. Diversifying crops into less water-intensive alternatives like sorghum further optimized resource use and sustained productivity under changing climate conditions.

The project strengthened resilience by reducing farmers' vulnerability to rainfall variability and water scarcity. Rational water management strategies and early sowing windows mitigated water stress during critical crop growth stages, decreasing dependence on erratic monsoon rains (Figure 9 and Figure 10). Substituting water-intensive crops reduced seasonal irrigation demands by up to 90%, conserving groundwater resources and ensuring agricultural stability (Barati et al., 2024). Environmental benefits included reduced carbon emissions from groundwater extraction and increased biodiversity due to diversified cropping patterns.

Figure 9:
Participatory implementation of co-designed early planting date.

Figure 10:
Participatory implementation of early planting date.

Economic and social benefits were equally significant. Enhanced yields and reduced resource dependency boosted farmers' economic resilience, while the participatory framework fostered community empowerment and inclusivity. Women farmers, often excluded from decision-making, actively participated in co-designing solutions, promoting gender inclusion. However, challenges such as financial constraints, limited access to advanced technologies, and knowledge gaps among farmers hindered broader adoption. Socio-cultural resistance to crop diversification and the limited involvement of the private sector in capacity building and market access were additional barriers. Policy and institutional support were instrumental but required further alignment to address systemic challenges. Expanding government subsidies, fostering private-sector partnerships, and conducting targeted awareness programs could accelerate adoption. The project highlights the need for holistic, multi-stakeholder approaches to overcome challenges and ensure long-term sustainability, offering valuable lessons for CSA in similar contexts.

Recommendations

To enhance the adoption of CSA in similar contexts, targeted strategies must address technical, financial, and institutional barriers. Scaling participatory frameworks that integrate farmers' inputs into solution design ensures relevance and builds trust, increasing adoption rates. Capacity-building programs tailored to local needs, such as training on advanced irrigation techniques and resilient cropping systems, are essential. Promoting community-based organizations can amplify knowledge-sharing and collective action.

For policymakers, aligning subsidies and incentives with CSA objectives, such as financial support for developing rain harvesting ponds and crop diversification, is critical. Establishing policies that encourage rainwater harvesting, groundwater recharge, and precision farming can create a conducive environment for sustainable practices. Researchers should prioritize context-specific solutions by integrating advanced modelling tools with indigenous knowledge, ensuring adaptability to local conditions. Practitioners must focus on simplifying technology and making it accessible to farmers, bridging the gap between innovation and plausible implementation.

Private sector involvement can be incentivized through tax benefits, co-funding opportunities, and recognition programs for businesses investing in CSA technologies or market linkages. Partnerships between governments, NGOs, and private entities can enhance resource mobilization and outreach. Encouraging public-private collaboration ensures sustainable and scalable implementation of CSA practices, fostering long-term agricultural resilience and productivity.

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2.5 Case Study 5: Climate-Smart Farming in the Himalayas: Advancing Food Security and Livelihoods under changing Climate

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Abstract

The study investigated how the climate impacted agriculture in Pakistan's HKH region. Moreover, adaptation strategies, barriers, institutional arrangements and farmers' willingness to adopt CSA practices were explored. A farm-level survey was conducted on farmers' experiences with climate change and adaptation behaviour. The study revealed that farmers were aware of the implications of climate change in agriculture. The adoption of CSA was limited to crop rotation, diversification, and ridge planting (potato). Because of the limited adoption of CSA, site-specific CSA practices at low, medium and high altitudes were identified for crops and livestock farming. The project recommended site-specific CSA, including zero tillage, agroforestry, water conservation and changing crop type, crop varieties, sowing dates and organic manuring for crop growers, while cross breeds, feed and shed management for livestock farmers. Farmers were trained to prepare silage/feed, which enhanced milk and mean production. The recommended practices increase the resilience of crops and livestock and improve yield sustainably.

Background

Hindu Kush Himalayas (HKH) is the home and source of livelihood for more than 200 million people living in the mountains, from which around 52 million inhabit Pakistan's territory- Gilgit-Baltistan (GB). Future projections show a 1.4 °C–3.7 °C increase in mean temperature in Pakistan by 2060, with the GB (north), potentially experiencing higher temperatures. Changes in monsoons and rising temperatures will pose substantial challenges to agriculture and dependent households in the area. Climate change-triggered extreme events are estimated to cost 1.5 to 2% of the country's GDP. Agriculture is overwhelmingly represented by small-scale monoculture or bi-culture subsistence farms. Farmers are less resourced, and their livelihood is primarily agriculture, mainly crops and livestock. Decreasing winter temperatures pose serious challenges for small farmers when feeding their livestock. Consequently, farmers either sell their animals before the onset of winter or feed them on husk collected during summer months, when the tree leaves and sometimes crushed food grains are fed, which poses food availability issues for households. Due to hilly terrains, land erosion is significant during the Monson, exacerbating the risk of reduced yields or no cropping. A water storage system does not exist at the farm level, which is another bottleneck for summer, requiring more water with rising temperatures. Due to cultural issues, agriculture is mainly done by male farmers, with minimal role of female members in the decision-making process. Monocropping (potato) in some areas for the last 2 decades has imparted irreparable losses to the land, hampering its ability to grow other crops, crop disease occurrences, and complete losses to the farm households. Traditional adaptation strategies to lessen the impacts of rapidly unfolding climatic events have become redundant, hence, sustainable agriculture necessitates climate-smart solutions to be identified, upscaled, and validated at the local levels for improved food security.

Rationale

The HKH region in Pakistan inhabits over 50 million people, and this depends on subsistence mountainous farming. However, climate change poses significant challenges to these already vulnerable agroecosystems. Traditional agricultural practices are disrupted by climate change, altering weather and rainfall patterns, and glacial melt. Despite the growing recognition of these challenges, limited research exists on the socio-economic and environmental dynamics that shape farmers' adaptation strategies (Mishra et al., 2019). Moreover, many existing studies (e.g. Zahoor et al., 2021), adopt top-down approaches, often overlooking local socio-economic factors and adaptation behaviour, which are vital for designing effective interventions. This study addresses this gap by analysing farmers' perceptions of climate change and identifying climate-smart agricultural (CSA) practices that reduce farm-level vulnerabilities. We conducted surveys at three altitudes (valley, medium, and high altitude), making a total sample size of 120 households (40 at each altitude) through stratified random sampling to identify CSA practices (Figure 11). The data were analysed to determine the replicable CSA practices and the farmers' hindrances in adapting their respective CSA practices.

Figure 11:
Household data collection by project team.

Farmers observed the significant impacts of CC on crops and livestock, impacting their livelihood through reduced productivity and sometimes crop failure. Certain CSA practices were successfully implemented in one area, while farmers in other zones were unaware of their benefits. After analysing the data, zero tillage, crop diversification, rainwater harvesting, agroforestry, crossbreeding livestock, and organic manuring were recommended per the farm dynamics across three elevations. The findings highlight the potential of local, low-cost CSA practices to enhance soil fertility, crop yields, and livestock productivity and improve livelihoods. The lack of institutional support for adopting CSA practices was a major bottleneck. By scaling these practices across similar agro-ecological settings, the study provides insights for thinkers and policymakers to design area-specific strategies for supporting high-altitude farmers in adapting to climate change.

Proposed Solution

The project successfully implemented the identified Climate-Smart Agriculture (CSA) practices in Pakistan's Hindu Kush Himalayan (HKH) region. One of the primary techniques, rainwater harvesting, was suggested across all three altitude gradients. This technique applies throughout the HKH region because water flowing from uphill can be captured and stored in downhill reservoirs for dry season use. The efficiency of harvested rainwater could be maximized by integrating it with localized irrigation systems (i.e. drip irrigation). It is recommended that the government devise a policy to subsidize the rainwater harvest in the HKH region through low-interest loans for smallholders to develop water storage infrastructure. Zero tillage- a cost-effective CSA- was recommended and widely adopted by peasants. Farmers were educated on the benefits of this technology (soil moisture conservation, improved soil health) at significantly less labour cost. Similarly, crop diversification was recommended to address land degradation caused by decades of continuous monocropping (potato) contracted by a multinational company. Farmers were encouraged to cultivate multiple crops and practice agroforestry to restore soil health and increase farm income.

Feeding livestock during winter was another challenge addressed by training farmers to prepare silage/fermented feed from maize husks, which are storable for extended periods. This simple and cost-effective technique was well-received by farmers due to its practicality. Farmers were advised to crossbreed their milking animals with high milk-yielding varieties for livestock improvement to increase dairy productivity. This intervention was particularly valuable for smallholder farmers, as it provided an opportunity to increase household income through higher milk production. The team emphasized the importance of selecting breeds resilient to local climatic conditions and guided them in seeking veterinary support.

Significant gaps were identified in government support, such as the absence of adequate market linkages, limited access to extension services and no timely warning about weather. Farmers were concerned over the lack of institutional support for improved connectivity of rural markets with urban centres to fetch higher prices for their produce. Surprisingly, many extension workers were unaware of the latest CSA practices. To address this, the team developed comprehensive training manuals and workshops for government officials, including extension workers and agricultural officers (Figure 13). These manuals covered key concepts related to climate change, disaster risks, and CSA practices, equipping stakeholders with the knowledge needed to support farmers effectively.

For wider dissemination of CSA knowledge, the project collaborated with community-based organizations (CBOs) and their representatives were trained to transfer CSA knowledge to farmers. However, due to legal constraints, the role of non-governmental organizations (NGOs) in community awareness-raising on climate change remained limited. The project highlighted the critical role of government in building farmer capacity, providing subsidies for smallholders, and improving infrastructure for transporting agricultural produce to markets. Enhanced market access would allow farmers to earn better incomes, enabling them to invest in CSA practices, conserve the environment, and improve household livelihoods.

Major barriers to CSA adoption included limited access to resources, smaller production units, inadequate marketing services, and poor institutional outreach. The project emphasized the need for capacity-building programs tailored to area-specific CSA practices to improve farmer livelihoods and ensure food security in the highlands. The study recommended strengthening institutional services related to climate adaptation, including timely weather forecasts and improving local market linkages. Investments in rural infrastructure, such as roads and transportation networks, were identified as crucial for increasing farmer profitability. The study demonstrated that simple, cost-effective, and easily adaptable CSA practices can significantly enhance resilience to climate change in the HKH region. Scaling up these interventions through government support and active involvement of local communities is crucial for ensuring long-term sustainability and improving the livelihoods of farming households in the HKH region.

Lessons Learned

The project yielded valuable results regarding the adaptability of recommended CSA practices. Primary benefits included raising awareness of climate change issues and presenting practical solutions to all stakeholders, including farmers, agricultural officers, and representatives of community-based organizations (CBOs), and encouraging the adoption of CSA in response to ever-changing climatic conditions (Figure 13). The prescribed CSA practices significantly improved crop yields and dairy production while minimizing disturbances to natural ecosystems, conserving biodiversity, and reducing GHG emissions. The financial gains associated with recommended CSA can make agriculture more appealing to the younger population. The involvement of the young population in agriculture businesses may generate employment opportunities and poverty reduction in the region.

However, several challenges limited the broader implementation of CSA. Smaller production units were the significant shortcoming towards the low adoption of CSA practices. Smallholders often struggle to invest in new technologies. This can be addressed by establishing cooperatives to pool resources and enabling smallholders to access and implement CSA technologies effectively. Another challenge was the minimum involvement of female farmers, primarily due to cultural norms. Despite having an integral role in agricultural activities, women have limited participation in decision-making and access to resources. This can be addressed by promoting value addition to agricultural products, including processing and grading/packaging fruits and vegetables, which women can do at home to empower them to enhance household income and support CSA practices.

Furthermore, private banks should lower their minimum landholding thresholds to support most smallholders in the area rather than financing only big farms. Expanding financial services for smallholders would ensure a more equitable distribution of resources and opportunities. Finally, a coherent agricultural policy needs to be tailored to the local context to address the specific challenges faced by farmers in the HKH region and provide an enabling environment for CSA adoption on a larger scale.

Figure 12:
Meetings with farmers and representatives of CBOs.

Figure 13:
Training workshops on CSA for government officials in highlands.

Recommendations

The involvement of farmers, extension workers, policymakers, and private sector representatives is significant for the effectiveness of CSA initiatives. Building capacity for extension workers is also essential for implementing CSA practices. Given the similar terrains in the HKH region, CSA practices successfully implemented in one area can be adapted and upscaled in other HKH countries at comparable altitudes. Establishing a regional knowledge-sharing platform on CSA is recommended to provide accessible resources for farmers and practitioners. Regional organizations like ICIMOD can lead in replicating CSA practices from one HKH region to another.

Additionally, improved farmer-to-farmer connectivity to share practical experiences can significantly encourage the adoption of CSA on a larger scale. Training modules developed under this project can be translated into local languages to ensure accessibility for farmers and practitioners in similar contexts. Considering the vulnerability of the HKH region to climate change-induced disasters, governments must devise area-specific agricultural policies, thereby integrating CSA as a core component of regional agricultural frameworks to address climate resilience and sustainability. Finally, Governments should incentivize private sector co-financing for CSA upscaling through area-specific financing models. Such initiatives would develop a CC-resistant and food-secure HKH region.

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3. Climate-Smart Agricultural Technologies and Practices

Climate-smart agricultural technologies and practices play a pivotal role in enhancing the resilience of highland farming systems to climate change. These innovations focus on improving soil health, optimizing water use, and increasing crop productivity while minimizing environmental impacts. By integrating sustainable land management techniques, precision irrigation, and agroecological approaches, farmers in highland regions can mitigate climate risks and enhance long-term agricultural sustainability.

Using some selected case studies, this section explores the innovative technologies and practices that comprise Climate-Smart Agriculture (CSA). CSA is an approach to managing landscapes—cropland, livestock, forests, and fisheries—that addresses the interlinked challenges of food security and climate change.

CSA technologies and practices are essential for achieving three main goals. First, they aim to increase agricultural productivity and incomes to improve food security and livelihoods. Second, they seek to enhance the resilience of farming systems to climate change impacts, such as droughts, floods, and extreme temperatures. Finally, CSA aims to reduce greenhouse gas emissions from agricultural activities and promote carbon sequestration in soils and biomass.

Various CSA technologies and practices can be adopted in the highlands, depending on different farming systems' specific needs and contexts. Some key technologies and practices include:

- **Sustainable Water Management**: Implementing efficient irrigation systems, such as drip irrigation and micro-sprinklers, and promoting water conservation techniques to reduce water consumption and enhance water availability.
- **Soil Health Improvement:** Increasing soil organic matter by adding compost, biochar, and cover crops to enhance soil fertility, water-holding capacity, and nutrient retention.
- **Crop Diversification:** Cultivating a broader range of crops, including drought-tolerant and heat-resistant varieties, can help reduce the risk of crop failure and enhance food security.
- **Agroforestry:** Integrating trees and shrubs into crop fields to provide shade, windbreaks, and additional income sources while improving soil fertility and biodiversity.
- **Sustainable Livestock Management:** Implementing rotational grazing systems, improving animal health and nutrition, and promoting manure management to reduce greenhouse gas emissions and enhance livestock productivity.
- **Renewable Energy:** Utilizing renewable energy sources, such as solar or wind power, to reduce reliance on fossil fuels and lower the carbon footprint of agricultural activities.
- **Precision Agriculture:** Digital technologies, such as sensors, drones, and geographic information systems (GIS), are employed to monitor crop health, optimize resource use, and enhance agricultural decision-making.

Continuous innovation is crucial for developing and adapting CSA technologies and practices to highland agriculture's specific needs and challenges. This includes investing in research to identify and promote new CSA technologies and practices suitable for highland conditions, facilitating knowledge transfer and technologies from research institutions to farmers and communities, and encouraging farmer-led innovation and experimentation to adapt CSA practices to local contexts.

Adopting CSA technologies and practices can lead to numerous benefits, including increased productivity, enhanced resilience, reduced emissions, improved soil health, increased biodiversity, enhanced water security, and empowered communities.

3.1 Case Study 6: Climate-Smart Water Management Practices in Nan

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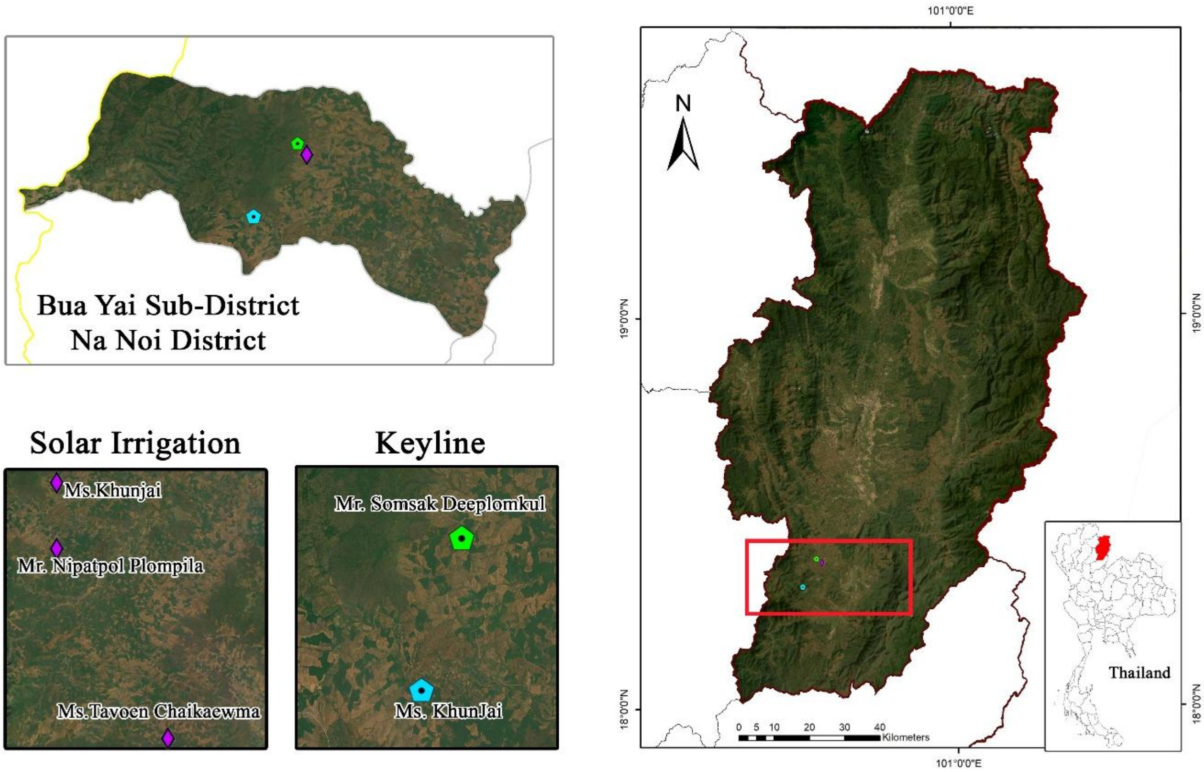
Abstract

Solar irrigation and keyline ploughing are two climate-smart water management practices used in highland agriculture in the Bua Yai subdistrict of Na Noi district, Nan province. Solar irrigation systems can reduce greenhouse gas emissions by up to 3,067 kg CO2e per hectare. These systems also help farmers adapt to climate change, enabling them to grow crops year-round, which enhances food security for highland farmers. Keyline ploughing, on the other hand, is effective for retaining soil moisture for extended periods but works best in areas with gentle slopes. Our demonstration plots have shown that the moisture content in the soil can be up to 1.5 times higher with keyline ploughing compared to areas without this practice, depending on the slope and water availability in the region.

Background

Nan Province is in the upper northern region of Thailand, approximately 668 kilometres from Bangkok via Highway 101. It covers an area of roughly 7.58 million rai (with 1 hectare equivalent to 6.25 rai), of which 87.2 percent is mountainous, reaching altitudes of approximately 2,115 meters above sea level. The Nan River originates in this province and flows from north to south. The flat plains constitute only 12.8 percent of the total area (Figure 14).

Figure 14:
The location of the solar irrigation and keyline ploughing pilot demonstration sites.



According to population registration data from September 2021, Nan Province has a total population of 475,915 with 238,071 males and 237,898 females. Due to the predominant mountainous terrain, most farmers engage in highland agriculture. However, highland agriculture faces several significant problems, including severe soil erosion, soil degradation caused by monoculture practices, soil, and water pollution stemming from sloping topographies, the overuse of fertilizers and pesticides, and high levels of sedimentation in water bodies, all of which contribute to a reduced carrying capacity (Zeng et al., 2018).

Nan Province, including the Nanoi District area, faces a water shortage and extended drought due to the demand for water sector services, increased deforestation, and the effects of climate change. (Baicha, 2016; Chuensin et al., 2021). Nan Province's climate challenges, including rising temperatures, increasing droughts, soil degradation, erosion, and heightened risks of flooding and wildfires, are worsened by unsustainable land management practices, which further contribute to environmental degradation. To address these challenges, Nan must implement climate adaptation and mitigation strategies. These strategies should include sustainable agricultural practices, forest conservation, improved water management, and community-based resilience-building initiatives. By tackling these challenges, we can protect Nan's ecosystems and ensure its agricultural sector's and local communities' long-term well-being (Promping and Tingsanchali, 2022; Kruasilp et al., 2024).

Future weather forecasts for Nan Province indicate that the minimum temperature is expected to vary across three distinct periods: the Near Future (2015-2045), the Mid Future (2046-2076), and the Far Future (2077-2100). This analysis is based on all six CMIP6 Global Climate Models (GCMs) under the SSP2-4.5 and SSP5-8.5 scenarios. The minimum temperature is projected to increase steadily, averaging an increase of 1°C during the Near Future and 2°C during the Mid and Far Future periods under both scenarios. Similarly, the maximum temperature is expected to rise by an average of 1°C in the Near Future and 3°C in the Mid and Far Future periods under the exact scenarios. Rainfall is also projected to increase in the coming years. In the Bua Yai subdistrict and Na Noi district, rainfall is expected to rise by 2-4% in the Near Future, 8-11% in the Mid Future, and 16-19% in the Far Future under the SSP2-4.5 scenario (TA 9993-THA, 2024).

Rationale

Highlands are vulnerable ecosystems that provide essential services like water, biodiversity, food, and beautiful landscapes. Although agriculture remains the primary economic activity in these mountainous regions, it has not received sufficient research attention. This view is outdated, as northern mountain agriculture has significantly evolved due to various development programs and has shifted mainly towards cash cropping on permanent fields (Trebuil et al., 2000; Tungittiplakorn and Dearden, 2002)

Soils in mountainous areas are primarily rocky, shallow, and lacking in fertility. They have a low capacity to retain water and experience high erosion rates, which limit their suitability for agriculture (Vityakon et al. 2004). As a result, farmers must apply large amounts of chemical fertilizers to maintain soil quality and productivity, which increases production costs. Water frequently becomes a limiting factor for mountain agriculture due to prolonged dry seasons and irregular rainfall patterns during the rainy season.

In northern Thailand, particularly in Nan Province, highland farming significantly contributes to deforestation. The monoculture of maize for animal feed leads to severe soil erosion and contamination from pesticides and heavy metals. Additionally, burning maize stubble after harvest worsens air pollution, increasing fine particulate matter (PM 2.5) levels, which poses health risks and negatively affects tourism due to reduced visibility.

Climate-smart agriculture, disaster risk management, biodiversity conservation, and ecosystem restoration are vital for adapting to climate change in Nan Province and other highland areas. A comprehensive approach that combines sustainable farming, efficient water management, community engagement, and climate-responsive infrastructure is necessary to build resilience effectively.

Collaboration among government, local communities, and the private sector is essential for building a climate-resilient Nan Province. Aligning local policies with national climate goals, integrating clean energy solutions, and encouraging community participation are crucial for long-term sustainability.

Proposed Solution

Bua Yai Subdistrict, located in Na Noi District, Nan Province (see Figure 1), faces a significant challenge: a water shortage for agriculture. Farming is traditionally limited to the rainy season, with rice grown in flat areas and maize on the hills for animal feed. This long-standing practice has resulted in soil erosion and reduced fertility.

Changing weather patterns have also increased costs due to higher reliance on chemical fertilizers and herbicides, pushing farmers further into debt amid declining yields and unpredictable prices. Additionally, soil erosion and herbicide contamination threaten local water sources used for drinking and agriculture.

Climate-smart agriculture (CSA) transforms agri-food systems through sustainable practices that support the Sustainable Development Goals (SDGs) and the Paris Agreement. It focuses on increasing productivity, enhancing climate resilience, and reducing greenhouse gas emissions. In the Bya Yai area, solar irrigation systems and keyline ploughing (Figure 15 and 16 respectively) address these challenges (Khamkhunmuang et al., 2022).

Solar irrigation systems effectively solve climate change challenges in Nan Province, Thailand, where agriculture relies on water availability. These systems allow farmers to sustainably tackle water scarcity, rising temperatures, and unpredictable weather.

Farmers can pump water reliably in remote areas by using renewable solar energy, reducing their dependence on costly and unreliable fossil fuels or grid electricity. This is increasingly important amid rising droughts and irregular rainfall patterns.

Solar-powered irrigation enables farmers to irrigate crops during dry spells while minimizing greenhouse gas emissions compared to diesel or electric systems. They also enhance water efficiency through integration with drip or sprinkler methods, reducing evaporation and waste.

While the initial investment is higher than conventional systems, solar irrigation offers long-term savings by lowering energy costs, making it a cost-effective option that improves resilience to extreme weather events (Verma et al. 2018).

Keyline ploughing is a land management technique that follows the land's natural contours to improve water retention and reduce soil erosion. Developed by Australian farmer P.A. Yeomans in the 1950s, it is part of his Keyline Design system, which emphasizes landscape design, water management, and ecological restoration.

The key principles of keyline ploughing include:

(1) **Contour Ploughing:** This involves ploughing along the land's contours to create channels that slow down runoff and promote water retention.
(2) **Subsoiling:** This process breaks up compacted soil layers to enhance water infiltration.

Specialized keyline ploughs create furrows and channels that help retain water and direct runoff effectively.

In the Bua Yai area, we have installed solar water irrigation systems in three locations:

(1) At the demonstration plot of Mrs. Thawan Chaikaewma, situated in Village No. 8, Ban Nong Ha (0.8 ha).
(2) At the demonstration plot of Mrs. Khwanchai Khaeangriangkhwang, located in Village No. 2, Ban Mai Mongkhon (1.92 ha).
(3) At the demonstration plot of Mr. Nippatphon Phromphila, found in Village No. 4, Ban Thap Man (1.44 ha).

The conditions for installing a solar irrigation system include:

- The agricultural area must have legal ownership.
- There must be a reliable water source available year-round.
- The farmer must be committed to caring for the equipment and following the project's guidelines.

Keyline ploughing has been carried out in two areas:

- Mr. Somsak Deepromkun's agricultural area in Village No. 4, Ban Thap Man.
- The farm area of Mrs. Kwanjai Khaewriangkhwang in Village No. 2, Ban Mai Monghol.

The criteria for selecting areas for Keyline ploughing include:

- The farm area must have legal ownership.
- The area should not be too steep.
- Proximity to a water source is highly preferred.

Figure 15:
Solar Irrigation in Bua Yai.

Figure 16:
Keyline Ploughing in Bua Yai.

Lessons Learned

Solar Irrigation

Due to the relatively short monitoring and evaluation periods, we have opted for a straightforward method to assess electricity generation capacity. We calculate capacity based on the number of solar panels installed in each demonstration area and compare it to the greenhouse gas emissions produced per watt of electricity generated.

(1) Greenhouse Gas Emission Reduction

Table 2:
Solar electricity generation of panels compared to the greenhouse gas emissions per unit of electricity produced.

Items	Village 8	Village 2	Village 4
No. of solar Panel*Watt	8*410/1000	18*410/1000	14*410/1000
Generation capacity	3.28 KW/day	7.38 KW/day	5.74 KW/day
One day, the maximum solar power is 5 hours, and 1 year has 265 days.	4346 KW	9778.5	7606.5
Reduce GHG emission (kgCO2e) (KW*EF)/Yr	2529.81	5692.06	4427.16
Equal to planting a tree	316.23 Trees	711.51 Trees	553.40 Trees

Emission Factor of electricity (1 Unit)=0.5821 (IPCC, 2006)
One tree absorbs CO_2= 8 kg (Thailand Greenhouse Gas Organization)

(2) Solar-powered irrigation systems enable farmers to irrigate crops during dry spells without worrying about water shortages.
(3) These pumps also provide controlled water distribution, minimizing evaporation and runoff waste.

Keyline ploughing:

Two demonstration areas were ploughed using the keyline method, with soil moisture monitoring in three conditions: without keyline ploughing, with keyline ploughing, and with keyline ploughing plus additional watering. Results showed higher moisture content in areas with keyline ploughing, especially watered areas. Statistically, moisture levels significantly differed between keyline-ploughed and non-keyline-ploughed areas. Keyline ploughing also releases approximately 42 kg of CO2 equivalent per hectare (see Figures 3 and 4).

Insufficient joint investments from the public and private sectors hinder the development of solar irrigation systems in highland areas, limiting farmers' access to equipment. The Bank for Agriculture and Agricultural Cooperatives could help by providing low-interest loans to promote adoption.

Keyline ploughing faces a significant limitation: specialized equipment may not be readily available to all farmers. It also works best on mild terrain, as steep slopes over 15% in Bua Yai can hinder its effectiveness.

Crops suitable for Keyline ploughing, like grasses for animal feed, may have limited lifespans since Keyline ploughing must be done every 4 to 5 years.

Recommendations

Creating an environment with financial incentives, knowledge transfer, and community involvement is essential to promote Climate Smart Agriculture (CSA), particularly solar irrigation and Keyline ploughing in the Bua Yai subdistrict, Na Noi district, Nan Province, and similar areas. Collaboration among farmers, government agencies, NGOs, research institutions, and the private sector is vital for scaling CSA practices, helping farmers adapt to climate change, and ensuring sustainability.

For Climate-Smart Agriculture (CSA) to succeed in Nan Province, collaboration among policymakers, researchers, and practitioners is essential. Policymakers should develop supportive policies and provide funding while researchers focus on local solutions. Practitioners, including farmers and extension workers, are critical for implementing CSA practices. By addressing each group's challenges, CSA can help farmers adapt to climate change, boost productivity, and build resilience.

Encouraging private sector participation in Climate-Smart Agriculture (CSA) requires financial incentives, regulatory support, and market access. By creating favourable investment conditions, policymakers can stimulate sustainable practices. The private sector can provide the capital, expertise, and technology needed to scale CSA and promote agricultural sustainability.

Strategies such as financial support programs, technical training, stronger policy frameworks, and awareness campaigns are essential for addressing these challenges. A multi-stakeholder approach that includes the government, private sector, NGOs, and local communities can facilitate successful adoption. By integrating financial support, technical training, institutional backing, and awareness initiatives, the adoption of solar irrigation and keyline ploughing can be significantly increased in the Bua Yai Subdistrict, ensuring long-term sustainability in water management and agricultural productivity.

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3.2 Case Study 7: Climate-Smart Soil Management

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Abstract

Climate change poses significant challenges to agriculture through increased temperatures, unpredictable rainfall, and extreme weather events, threatening food security and livelihoods globally. A shift toward sustainable and climate-sensitive agricultural practices is imperative. Climate-smart agriculture (CSA) offers an integrated approach to enhance productivity, resilience, and mitigation. This study identifies seven CSA practices suitable for the highlands of Nan Province, Thailand: solar-powered irrigation systems, biochar, keyline approach, organic composting, mulching, stress-tolerant crop varieties, and agroforestry. These practices address issues related to water scarcity and poor soil fertility, offering productivity gains; enhancing climate resilience of highlands agriculture; and reducing greenhouse gas (GHG) emissions. For instance, solar-powered irrigation and biochar enhance water use efficiency and soil quality. Mulching and organic composting offer affordable soil and land management solutions, while stress-tolerant crops and agroforestry bolster adaptation and mitigation. This research underscores the potential of CSA practices to transform agricultural soil management, emphasizing their efficacy in promoting sustainable livelihoods and combating climate change impacts.

Background

Global food production must increase by 70% by 2050 to meet the demands of population and income growth, with much of this increase needed in Asia, a region characterized by rapid population growth, widespread poverty, and low agricultural productivity (Wahlqvist et al., 2012). Nearly 38% of global land is used for agricultural activities (Müller, 2011), but the sector faces significant risks due to climate change (Bandara and Cai, 2014). Rising temperatures, extreme weather events, and sea level rise threaten agricultural yields and food security, particularly in developing countries with high dependence on farming. This is exacerbated by agriculture's significant contribution to GHG emissions (14% directly and 17% indirectly) through improperly managed activities (Azadi et al., 2021; IPCC, 2007, 2013). A shift to sustainable and resilient agricultural practices is thus essential to mitigate these challenges.

Countries like Thailand demonstrate diverse agricultural systems shaped by their climate and topography. The highlands in Nan Province and such are composed of varied terrains. These areas are highly climate-sensitive due to dependence on seasonal rainfall and fragile ecosystems prone to soil erosion and degradation. Agriculture remains the backbone of livelihoods, supporting rural communities and contributing significantly to the national economy. Smallholder farmers dominate, often lacking the necessary resources for adaptation, making them vulnerable to climate impacts. While growing, the private sector's involvement in agricultural supply chains is still insufficient to address the scale of challenges posed by climate change. Major climate change impacts in Nan Province include rising temperatures, increased frequency of droughts, and erratic rainfall patterns, which disrupt crop growth and reduce yields. Soil degradation from erosion and extreme weather events further exacerbates these issues. Addressing these vulnerabilities requires adopting CSA to enhance productivity, build resilience, and reduce emissions, aligning with global efforts to meet the Sustainable Development Goals.

Rationale

In regions like Nan Province, where agriculture forms the backbone of rural livelihoods, soil and crop management modernization focusing on changing climate adjustments could eventually cover all three pillars of CSA that are critical to sustainable agricultural development.

Increasing agricultural productivity sustainably. Adapting cultivation practices can sustainably enhance Thai farmers' productivity and income. For instance, cultivating climate-resilient crops/varieties with proper soil health management techniques can ensure higher yields even under variable climate conditions. Practices such as conservation tillage, mulching, and biochar application can improve soil health, enhancing water retention and nutrient availability, eventually boosting crop yields. Water-efficient technologies, such as solar-powered irrigation, further optimize resource use, safeguarding against water-scarcity while boosting agricultural output. These approaches align with national food security goals and provide a pathway to sustainable development.

Enhancing resilience to climate change. The vulnerability of Thai farmers to climate change necessitates a focus on adaptation. Adopting resource-conserving management practices plays a pivotal role in adapting to climatic extremes. Techniques like mulching and agroforestry reduce soil erosion, maintain soil moisture during droughts, and stabilize ecosystems against erratic weather patterns. Additionally, diversified cropping systems and soil conservation methods strengthen the resilience of farming systems, enabling them to recover faster from climate-induced shocks. These measures reduce farmers' dependence on favourable weather conditions and stabilize production in the face of climatic shocks, thereby safeguarding livelihoods.

Reducing greenhouse gas emissions. The agriculture sector contributes significantly to GHG emissions, yet practices, such as reduced tillage and biochar application, trap carbon in the soil while minimizing CH_4 and CO_2 release. Agroforestry and crop rotation practices sequester carbon and diversify income sources, creating co-benefits for farmers. These practices support Thailand's commitment to reducing emissions under its Intended Nationally Determined Contributions.

Proposed Solution

The CSA concept is gaining considerable attention in coping with the challenges of adapting agricultural practices to climate change. CSA originated from the acronym *SMART*, where *S* stands for specific, *M* for measurable, *A* for achievable, *R* for reliable, and *T* for timely (McCarthy et al., 2012). Hence, CSA is an integrated approach to developing agricultural strategies to secure sustainable food security under the adverse impacts of climate change (Das and Ansari, 2021). According to the Food and Agriculture Organization of the United Nations (FAO, 2010), CSA is a method of agriculture that sustainably increases productivity and resilience (adaptation) and reduces/removes GHGs (mitigation) while enhancing the achievement of national food security and development goals. It integrates a tri-dimensional approach to sustainable development (economic, social, and environmental) and a combined concern for food security and climate change (Terdoo and Adekola, 2014). Thus, CSA targets to provide a triple-sided win-win solution to food security, adaptation, and mitigation by sustainably increasing agricultural productivity and income (food security), adapting and building resilience to climate change (adaptation), and reducing and/or removing GHG emissions (mitigation). The following CSA practices have been proposed for implementation in the highlands of Thailand (Nan Province) to combat climate change impacts and enhance food security:

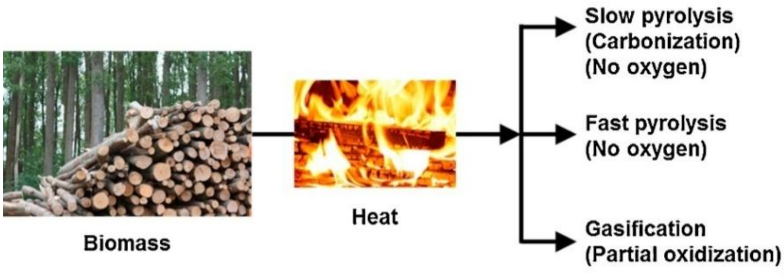
(1) Solar-powered irrigation system (Figure 17 and Figure 18)
(2) Biochar (Figure 19)
(3) Keyline approach (Figure 20)
(4) Traditional organic composting
(5) Mulching and soil cover (Figure 21)
(6) Stress (drought)-tolerant crop varieties, especially rice and maize (Figure 22)
(7) Agroforestry (Figure 23)

Figure 17:
A solar-powered pump at the Horticulture Innovation Lab's Regional Center at Kasetsart University, Thailand[1].

Figure 18:
Solar-powered irrigation system, pump running on electricity generated by photovoltaic panels[2].

[1] This pump can enable drip irrigation in remote locations where access to electricity, high costs of securing fuel, and distance from a water source can make irrigation prohibitively difficult for smallholder farmers
[2] Available online: https://www.climateaction.org/news/solar-irrigation-can-improve-prosperity-and-food-security-says-un-agency (accessed: 15 December 2024)

Figure 19:
Biochar production process and its properties[3]



Process	Product distribution (wt%) Solid	Liquid	Gas
Slow pyrolysis (Carbonization) (No oxygen)	35	30	35
Fast pyrolysis (No oxygen)	10	70	20
Gasification (Partial oxidization)	10	5	85

Figure 20:
Keyline plowing/subsoiling with Yeomans plow[4]

[3] Cha et al., 2016.
[4] Available online: https://permacultureapprentice.com/permaculture-water-management/ (accessed: 15 December 2024).

Figure 21:
Example of mulching practices. (A) Maise grown by adopting minimum tillage and mulching in Zambia[5]; (B) Rice straw mulching in chili in Thailand[6].

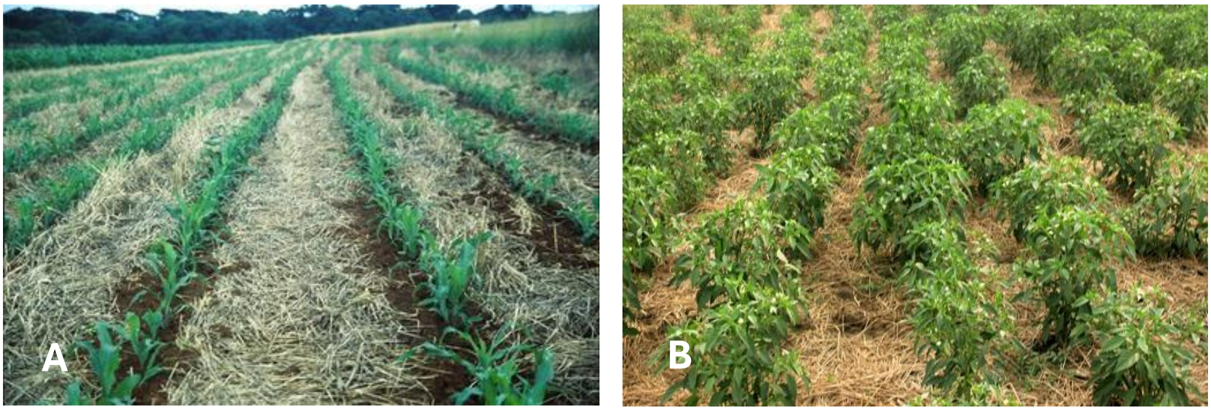


Figure 22:
Drought-tolerant hybrid maise at the Thai Department of Agriculture's Nakhon Sawan Field Crops Research Center[7].

[5] Branca et al., 2013
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Figure 23:
Different types of agroforestry practices – (A) Coconut and turmeric agroforestry system in Tamil Nadu, India[8]; (B) multilayered agroforestry practice with coconut-pineapple-millet[9]; (C) Coconut and ginger agroforestry system in the Philippines[10]; and (D) Keyline pattern cultivation under agroforestry system in the United States - Wisconsin[11].

Relevance of the proposed CSAs to the Highland Context

In the highlands of Thailand, these innovations are particularly relevant due to the region's fragile ecosystems and climate vulnerabilities. Solar-powered irrigation addresses water scarcity in remote areas by utilizing renewable energy. Biochar enhances soil health while sequestering carbon, which is critical in highland soils prone to erosion. The keyline approach ensures effective water management and soil conservation on sloped terrains. Mulching, soil cover, and organic composting improve soil fertility and moisture retention, while stress-tolerant crop varieties ensure yield stability amid climatic uncertainties. Agroforestry diversifies income sources and enhances ecological balance, contributing to productivity and resilience.

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Role of Stakeholders

(1) **Farmers:** Adoption of CSA practices is growing, but challenges remain, such as the high initial investment and lack of technical knowledge. Farmers benefit from increased yields, reduced costs, and improved climate resilience, but they need public and private sector support to overcome adoption barriers.
(2) **Private Sector:** Plays pivotal in financing technologies such as solar-powered irrigation and biochar production units. It also facilitates access to inputs, provides technical training, and creates market linkages for products, enhancing farmers' capacity and sustainability.
(3) **Government:** Supports CSA adoption through policies that offer subsidies for soil conservation projects, and incentives for farmers adopting sustainable practices. These initiatives align with Thailand's commitment to reducing GHG emissions under its Intended Nationally Determined Contributions.
(4) **Non-Governmental Organizations (NGOs):** NGOs are crucial in bridging knowledge gaps by offering training on CSA techniques and fostering community engagement. They organize cooperatives to enhance resource sharing, improve access to CSA technologies, and ensure equitable benefits for all stakeholders.

Lessons Learned

Implementing CSA practices in Nan Province, Thailand's highlands, provides critical insights into productivity gains, resilience, and environmental, economic, and social benefits. CSA practices, such as solar-powered irrigation, biochar, and mulching, have demonstrated tangible productivity improvements through increased yields and stabilized farming incomes. These interventions directly address climate vulnerabilities by reducing water scarcity risks and soil degradation. Practices like agroforestry and stress-tolerant crop varieties further enhance resilience by providing diversified income sources, improving food security, and supporting ecosystem services, such as soil stabilization and water retention. Environmental benefits are substantial, with biochar promoting carbon sequestration, reducing reliance on synthetic fertilizers, and agroforestry contributing to biodiversity conservation and emissions reduction. These practices collectively reduce the carbon footprint of farming activities while preserving natural resources.

On the economic and social fronts, CSA interventions create employment opportunities and reduce poverty through enhanced productivity and market growth. Gender inclusion can also be fostered by designing CSA initiatives that empower women, particularly in farming activities. However, several challenges persist. High upfront costs, especially for solar-powered irrigation systems and the Keyline approach, limit adoption among smallholder farmers. Knowledge gaps and socio-cultural resistance to adopting newer practices, such as the Keyline approach, impede broader implementation. Limited private sector engagement, especially in financing and technical training, further constrains the scalability of CSA technologies. While evolving, policy frameworks need strengthening to ensure sustained government investment in research and development for resilient crop varieties and incentivize CSA adoption through subsidies and grants. Addressing these barriers requires collaborative efforts among stakeholders to develop context-specific solutions, improve access to financial and technical resources, and foster community engagement. These lessons are vital for scaling CSA practices across highland regions and other vulnerable areas in Southeast Asia.

Recommendations

(1) Strategies to enhance the adoption of CSA practices in highland contexts like Nan Province, Thailand should address both the technical and socio-economic barriers.
(2) Policymakers should prioritize creating enabling environments through subsidies, low-interest loans, and tax incentives to make high-cost practices, such as solar-powered irrigation systems and the Keyline approach, accessible to smallholder farmers.
(3) Strengthening research and development on climate-resilient crop varieties and region-specific CSA technologies and establishing knowledge-sharing platforms for disseminating best practices is critical. Practitioners should focus on building farmer capacity through

community-led training programs and demonstration projects like the current one showcasing CSA practices' benefits.
(4) Greater private sector involvement can be incentivized through public-private partnerships that co-finance CSA projects, offer grants for technology development, and provide market linkages for CSA-based products.
(5) Establishing carbon credit systems for practices like biochar and agroforestry can attract investment while contributing to global emissions reduction targets.
(6) Researchers should work closely with local stakeholders to customize CSA practices to specific environmental and cultural contexts, ensuring farmer-centric solutions.
(7) Encouraging multi-stakeholder collaboration among government agencies, NGOs, and the private sector can amplify the impact of CSA adoption, effectively ensuring resilience, productivity, and sustainability in vulnerable highland regions.

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3.3 Case Study 8: Triple win of cassava-forage intercropping in highland agriculture: Soil fertility, cassava yield, and household income

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Abstract

This case study explores a transformative agricultural initiative in Yen Bai province, Northern Vietnam, aimed at addressing the challenges of monocrop farming on degraded hillslopes. Since 2003, local farmers have adopted cassava-forage intercropping as a sustainable practice, enhancing soil fertility, increasing cassava yields, and boosting household incomes. By planting forage grass along contour lines, this initiative has contributed significantly to climate resilience and socio-economic development in the region. Over 16 years, quantitative assessments reveal a 36–52% increase in cassava yields and a 38–59% rise in household incomes, alongside improved soil organic carbon and nitrogen levels. These findings highlight the potential for scaling this practice across similar highland regions, offering a practical solution to promote sustainability, productivity, and resilience in agriculture. This study demonstrates the vital role of stakeholder collaboration in advancing Climate-Smart Agriculture (CSA) strategies.

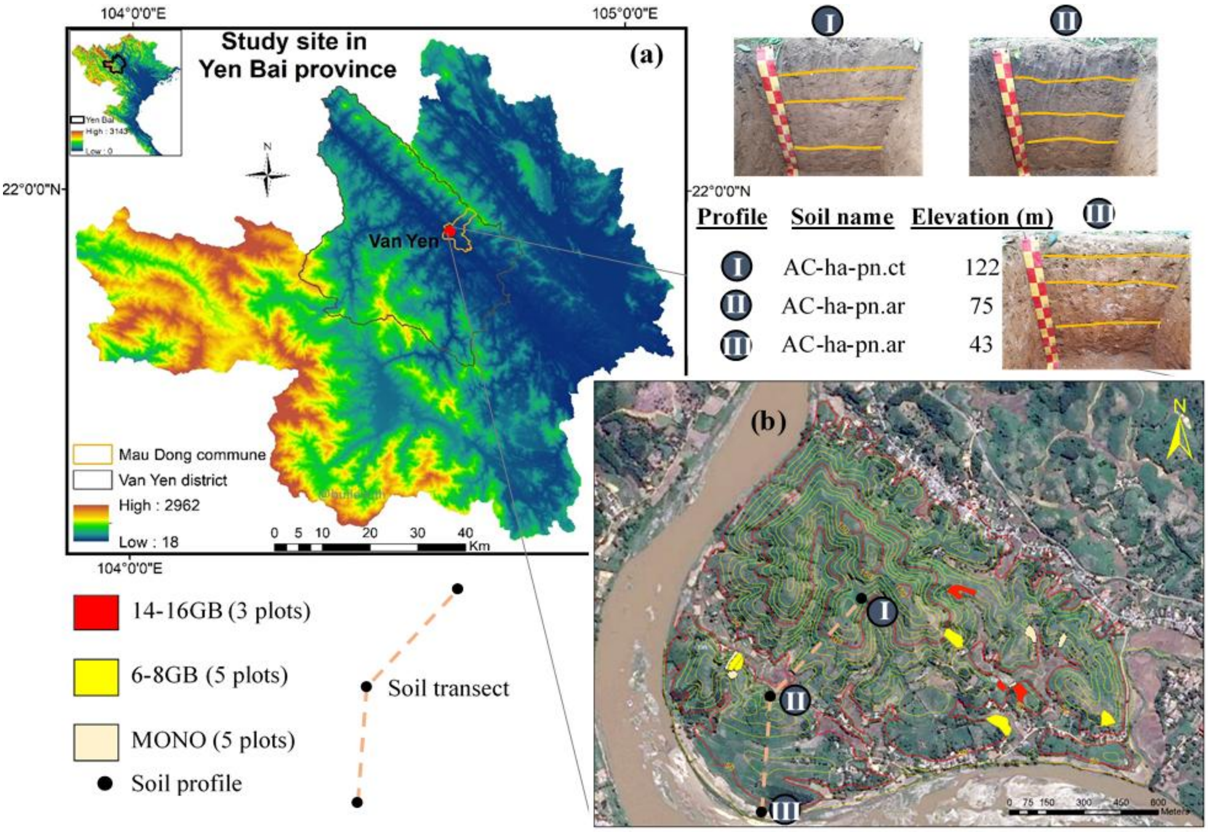
Background

The study area is located in the cassava-planted hillslopes of Cau Vai village (Figure 24), in Mau Dong commune, Van Yen district (Fig. 25a), Yen Bai province, Northern Mountain Region (NMR) of Vietnam. The dominant soil type is Acrisols, with a silt loam texture. Major crops in the area include cassava (Manihot esculenta C.), tea (Camellia sinensis), paddy rice (Oryza sativa), and tree crops such as cinnamon (Cinnamomum loureirii Nees), acacia (Acacia mangium), and eucalyptus (Eucalyptus sp.).

Due to limited grassland availability, farmers combine cut-and-carry feeding with free-range livestock production for cattle, pigs, and poultry. The climate is tropical monsoon, characterized by two main seasons: a rainy season (April–September) and a dry season (October–March), with a mean annual temperature of 22°C and total annual rainfall averaging 1,800 mm.

Local weather extremes have reportedly increased over recent decades, with more frequent hot and cold spells and higher rainfall intensity. These changes have exacerbated soil erosion and land degradation, particularly in unsustainably managed mono-crop systems. Häring et al. (2010) reported a significant decline in soil fertility following decades of upland agriculture after deforestation, with reductions of 60% in SOC, 67% in Nt, 91% in Ca^{2+}, 94% in Mg^{2+}, 73% in K^{+}, 75% in P, and a drop of 2.2 units in soil pH. Similarly, Tuan et al. (2015) documented topsoil losses of 174 tonnes/ha/year from maize monocropping on hillslopes.

Figure 24:
Study site in Cau Vai village, Mau Dong commune, Van Yen district, Yen Bai province[12].



Additionally, drought-induced hot spells have led to significant pest population build-ups in recent years, further reducing crop yields and exacerbating food insecurity. These challenges prompted the government of Van Yen district to launch a sustainable agriculture initiative in 2003, which has since demonstrated success.

Rationale

The study investigated three main plot categories: (i) cassava monocrop, (ii) cassava-forage intercropping of 6–8 years, and (iii) cassava-forage intercropping of 14–16 years. Soil sampling and household surveys were conducted to compare differences in soil fertility and household incomes across these categories. The findings revealed that longer durations of cassava-forage intercropping significantly improved soil organic carbon and total nitrogen, with statistically significant differences between the cassava monocrop and the two intercropping systems.

Soil physical properties, such as infiltration rate (the speed of water movement through the soil profile) and wet stable aggregates (soil clusters that retain stability when exposed to water), were also significantly better in the intercropping systems compared to the monocrop. Cassava yield increased by 36% and 52%, while household mixed incomes rose by 38% and 59% in categories (ii) and (iii), respectively, compared to category (i). While soil fertility, cassava yield, and household income were significantly higher in the two intercropping categories compared to the monocrop, differences between the intercropping categories were not statistically significant despite slightly higher values in category (iii) than in category (ii). This pattern follows the Law of Diminishing Returns, which explains the rapid improvements in soil fertility, cassava yield, and household income during the first half of the 16 years, followed by slower gains in the second half. These

[12] **Soil class**: AC-ha-pn.ct = Haplic Acrisol (Profondic, Cutanic); AC-ha-pn.ar = Haplic Acrisol (Profondic, Arenic) **Cropping system**: MONO (1) = Plots of mono-cropped cassava that never have had contoured forage barriers; 6-8GB (2) = Plots of cassava with contoured forage barriers implemented for 6-8 years; 14-16GB (3)

positive outcomes of the initiative help explain the overall socio-economic improvements observed among farmers in the area.

Proposed Solution

The findings provide evidence-based support that consistent implementation of the local initiative has led to improved soil fertility, increased crop yields, and higher household incomes, underscoring its potential for institutional adoption and scaling at subnational and national levels.

At the sub-national level, these findings provide a strong incentive and valuable support to other mountainous provinces grappling with the challenges of unsustainable agriculture, encouraging them to revise and adapt their annual and periodic development strategies and plans. Such changes will ultimately enhance the resilience of local agriculture and improve livelihoods in similar highland contexts. At the national level, when thoroughly assessed and integrated into policy reforms, this evidence can justify the allocation of national budgets to support sustainable agricultural practices through large-scale programs, guiding the design and implementation of relevant local strategies and initiatives. To effectively achieve revised evidence-based policies and strategies, synergies among stakeholders are essential.

Beyond being end-users and beneficiaries, farmers play a crucial role in the consistent and rigorous implementation of sustainable practices institutionalized in revised strategies and development plans. Successful implementers can become champion farmers, actively sharing their knowledge and experiences with peers to enhance technical capacities and contribute to achieving broader development goals.

Besides environmental benefits, CSA and NbS practices offer safer and better-quality produce to customers. The private sector, including intermediaries, SMEs, etc., is key in connecting CSA/NbS producers with the market through their existing channels. They can help bring information on food safety and quality by applying CSA and NbS practices to consumers and sharing market demands with producers to improve their production and business plans.

Non-profit and non-governmental organizations (NGOs), including national and international academic and research institutions, support national and subnational CSA and NbS strategies and development plans. These organizations contribute significantly to successfully implementing CSA and NbS initiatives by leveraging their technical expertise and fostering community engagement. Their technical strengths and forward-looking approaches help deliver tangible outcomes and impact that benefit farmers, align with local development goals, and facilitate the scaling of successful initiatives to national programs, particularly in highland regions.

Lessons Learned

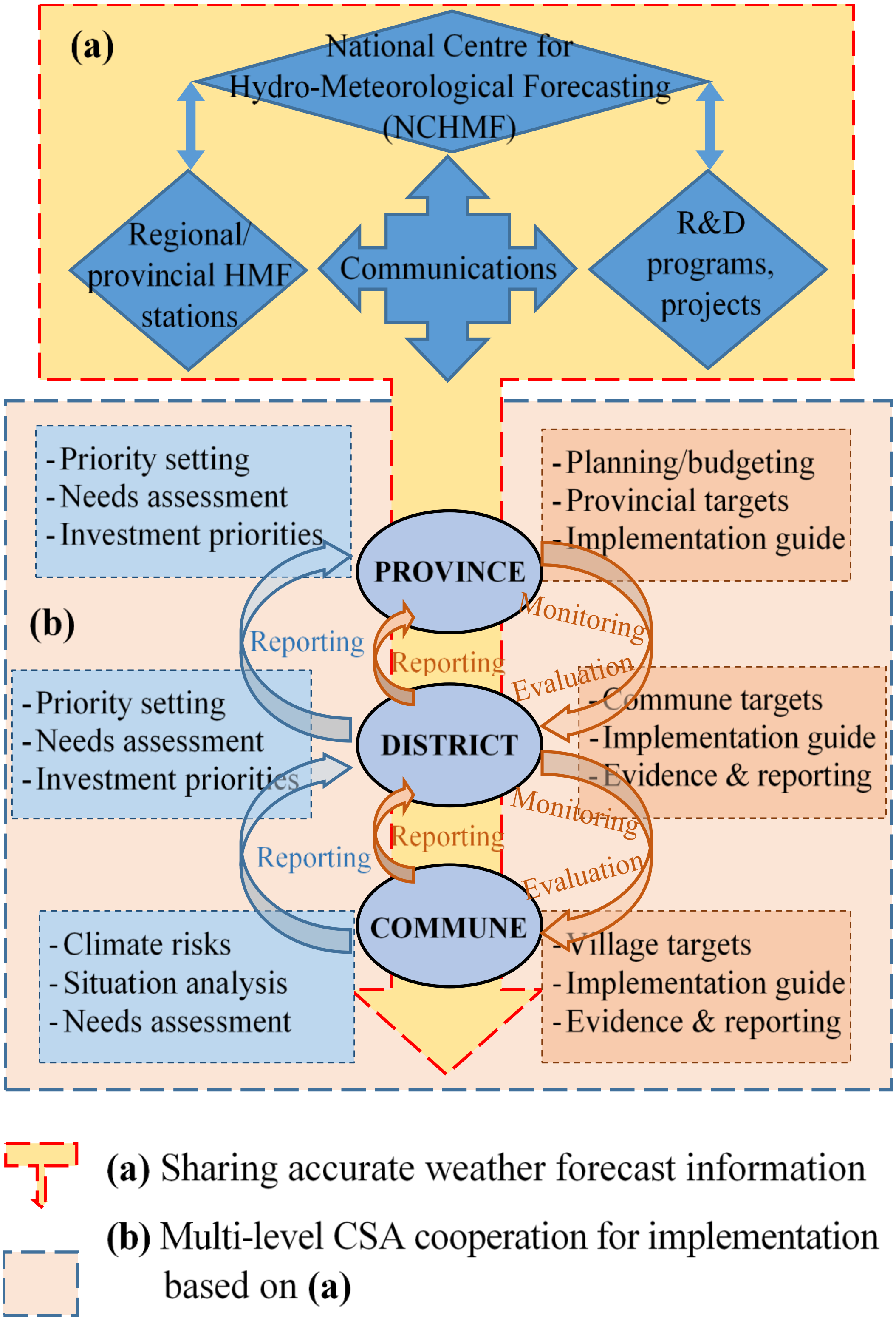
Over 16 years of implementing the local conservation agriculture initiative (since 2003) has significantly enhanced soil hydrological and physio-chemical properties, cassava yields, and farmers' incomes in the Van Yen district of the Northern Mountainous Region (NMR). Adopting contoured grass barriers has proven superior to conventional monocrop practices, particularly in improving wet soil aggregate stability, macro-aggregation, and water infiltration. Additionally, long-term use of contoured grass barriers notably enhanced infiltration rates during rainy and dry seasons, with higher rates observed near and above grass barriers compared to mid-alley positions. This study highlights that consistently implemented conservation agriculture initiatives can effectively rehabilitate soils degraded by unsustainable practices, restoring soil physio-chemical properties and improving local livelihoods in regions reliant on small-scale farming. Success depends on the concerted efforts of local governments and the strong commitment of farmers to transition their agricultural practices toward sustainability. This case underscores the importance of knowledge sharing and the development of flexible, policy-based adoption mechanisms to support sustainable agricultural practices.

Despite significant scientific evidence supporting the effectiveness of Climate-Smart Agriculture (CSA) practices, such as cassava-forage intercropping, their adoption and institutionalization at larger scales in Vietnam remain limited. This is primarily due to several barriers, including inadequate budgets and technical capacities, overlapping policies and programs, insufficient focus and investment in local communities and farmers, limited sharing of knowledge, data, and information, and weak cooperation and coordination in implementing sustainable agricultural programs across administrative levels.

Recommendations

Mainstreaming CSA into national and subnational initiatives and programs: Mainstreaming climate change responses into agricultural sector planning requires commune-level plans based on climate vulnerability and available resources. Effective irrigation measures include achieving over 80% active irrigation, demand investment in infrastructure, renewable energy, and coordinated multi-level plans. Stable internet and ICT support enable stakeholders to share weather data, plan jointly, and monitor CSA practices. Production organization is crucial, emphasizing climate insurance, services, and value chain development. Culture-based approaches should involve community education, village conventions, and gender equity to enhance resilience. Funding should be secured from diverse sources, including budgets, loans, and partnerships to support sustainable agricultural production and livelihoods.Multi-level cooperation and coordination in CSA implementation with climate advisory services: National and subnational initiatives require an action framework combining improved weather forecasting and coordination mechanisms. The climate component focuses on enhancing forecast accuracy through collaboration with hydro-meteorological stations and R&D programs using advanced models, enabling effective weather-driven adaptation strategies. Efficient communication and information sharing are essential for coordinated actions. The coordination component involves gathering climate vulnerability data and resource assessments from communal levels, aggregated at district and provincial levels to guide targeted investments, reducing budget waste. Strengthening bottom-up reporting and top-down guidance fosters collaboration across administrative levels, enabling better monitoring, evaluation, and achievement of adaptation and resilience goals in implementation (Figure 25).

Figure 25:
Recommendations for sharing accurate weather forecast information AND multi-level CSA cooperation for implementation of NTM's 2021-2030 strategy.



Further Reading

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3.4 Case Study 9: Capacity Enhancement of Himalayan Highland Communities through Development, Validation and popularization of Novel Multipurpose Pyrolizer cum Cooker for Climate Change Adaptation and Air Pollution Mitigation.

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Abstract

The Himalayan highlands, vital for India's apple production, generate approximately 1.49 million tons of pruning residues annually, often managed through open-air burning, contributing significantly to greenhouse gas emissions and climate change. To address this, a Multipurpose Pyrolizer cum Cooker was developed, offering a sustainable solution for residue management (Wani et al., 2023a; Wani et al., 2024) developed. The pyrolizer converts residue into biochar under controlled temperatures (400°C and 600°C), enhancing soil health, carbon sequestration, and crop productivity. Field trials using maize (Variety C-4) demonstrated improved soil physical, chemical, and biological properties, with increased nutrient availability, microbial activity, and water retention. Apple biochar at 600°C showed superior carbon sequestration and soil amendments. This patented technology has the potential to avert over 2.6 million tons of CO_2 annually while promoting clean cooking and socio-economic benefits, particularly for women. Its implementation can transform Himalayan agriculture into a climate-resilient and sustainable model, with implications for broader ecological and economic stability.

Background

The Himalayan highlands are a critical agricultural region characterized by a fragile ecosystem, rugged topography, and temperate climate. This region contributes 80% of India's total apple production, with 167,000 hectares under cultivation and an annual yield of 1.88 million metric tons. The agriculture system is largely rain-fed, dependent on the unique microclimatic conditions of the region (Mansoor et al., 2021). Open-air burning and traditional stoves significantly contribute to India's air pollution crisis. Annually, 23 million tonnes of crop residue are burned in Punjab and Haryana, contributing 30–40% of Delhi's PM2.5 levels during peak seasons. Traditional stoves, used by 56% of rural households, emit harmful pollutants, with indoor PM2.5 levels often exceeding 300–500 $\mu g/m^3$. Together, these sources account for 20–30% of India's PM2.5 emissions, causing 600,000 premature deaths annually from household air pollution and 17,500 deaths from crop burning. According to the National Family Health Survey (NFHS-5, 2019–2021), around 56% of rural households rely on solid fuels for cooking. These stoves emit high levels of particulate matter (PM2.5), often exceeding 300–500 $\mu g/m^3$ during cooking, far above the WHO's safe limit of 15 $\mu g/m^3$. This indoor air pollution is linked to 600,000 premature deaths annually, primarily from respiratory and cardiovascular diseases, with women and children most affected due to prolonged exposure. The soils are inherently fertile but prone to degradation due to steep slopes, high erosion rates, and limited vegetative cover, making sustainable land use crucial. Agriculture is the backbone of the local economy, providing livelihoods to over 70% of the population. Smallholder farmers dominate the landscape, practising subsistence farming. Apple orchards are a primary income source yet generate approximately 1.49 million tons of pruning residues annually (Wani et al., 2023b). Currently, the prevalent residue management strategies involve open-air burning or inefficient use in traditional stoves, both of which emit substantial greenhouse gases and degrade air quality. Women, who are central to agricultural and household activities, face significant health risks due to prolonged exposure to smoke. The region faces escalating climate challenges, including a clear upward trend in mean maximum and minimum temperatures. These changes amplify risks such as increased drought frequency, reduced soil moisture, and erosion. Soil degradation, including loss of organic matter and structure, further reduces productivity and resilience. These climate-induced challenges are compounded by the lack of effective residue management practices, which contribute to air pollution and greenhouse gas emissions.

In this context, there is an urgent need for innovative solutions that address both agricultural sustainability and climate resilience. The Multipurpose Pyrolizer cum Cooker has been developed to tackle these intertwined challenges. By converting residues into biochar, this technology not only provides a sustainable residue management alternative but also enhances soil health, reduces emissions, and supports livelihoods in the Himalayan highlands.

Rationale

The Himalayan highlands are an agricultural hub, producing 80% of India's apples, yet they face critical challenges from unsustainable residue management practices and climate change. The most common practice, open-air burning of approximately 1.49 million tons of pruning residues annually, contributes significantly to greenhouse gas emissions and soil degradation, while traditional residue use in stoves exacerbates air pollution and health risks. This necessitates a sustainable, integrated solution to mitigate these environmental, economic, and social challenges.

The development and deployment of the Multipurpose Pyrolizer cum Cooker address all three pillars of Climate-Smart Agriculture (CSA):

Increasing Agricultural Productivity Sustainably. By converting apple residues into biochar, the pyrolizer improves soil fertility, structure, and water retention capacity. Field trials using maize demonstrated enhanced nutrient availability, microbial activity, and crop yields. This provides a pathway for sustainable intensification of agriculture, improving productivity without expanding land use.

Enhancing Resilience to Climate Change. The biochar produced helps sequester carbon in the soil, improves its capacity to retain moisture, and reduces susceptibility to erosion. These benefits enhance the region's resilience against rising temperatures, erratic rainfall, and prolonged droughts. Farmers gain an adaptive edge, securing livelihoods in a climate-sensitive zone.

Reducing Greenhouse Gas Emissions. The pyrolizer eliminates the need for open burning of residues, significantly reducing CO_2, methane, and particulate emissions. The technology supports clean cooking, reducing indoor air pollution and improving household health, particularly for women. This innovative, patented technology directly addresses climate change mitigation and adaptation while ensuring sustainable agricultural development. It empowers Himalayan farmers with an eco-friendly residue management strategy, simultaneously contributing to environmental restoration, livelihood security, and gender equity.

Proposed Solution

The Multipurpose Pyrolizer cum Cooker represents a transformative, climate-smart innovation tailored to address key agricultural and environmental challenges in the Himalayan highlands (Figure 26). This patented technology tackles residue management, enhances agricultural productivity, and builds climate resilience. By converting apple pruning residues into biochar and serving as a clean cooking appliance, it integrates environmental sustainability with practical benefits for highland communities.

The pyrolizer incorporates several climate-smart practices, including biochar application, which improves soil structure, nutrient availability, water retention, and carbon sequestration. Its clean cooking technology reduces indoor air pollution, eliminating reliance on traditional stoves. Additionally, it provides a sustainable residue management solution that mitigates greenhouse gas emissions from open-air burning while promoting water conservation by improving soil moisture retention, essential for drought-prone highland areas.

This innovation is uniquely suited to the Himalayan context. Its energy efficiency ensures optimal performance in cold, high-altitude conditions while reducing dependence on fuelwood. By utilizing abundant apple pruning residues, the pyrolizer transforms waste into value-added biochar, enhancing adoption among farmers who value its dual utility as a pyrolizer and a cooking tool. Furthermore, the technology supports climate adaptation by improving soil resilience to erratic weather patterns, conserving water resources, and addressing the ecological fragility of the region.

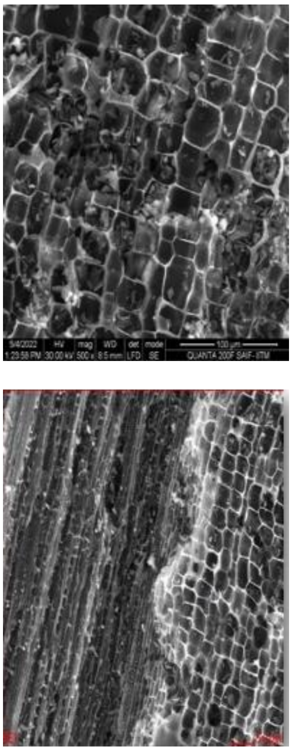

Figure 26:
Microstructure of the biochar.

Figure 27:
The pyrolyzer.

The successful deployment of this technology relies on collaboration among diverse stakeholders:

(1) **Farmers:** Early field trials show increasing farmer interest in the pyrolizer, particularly due to its dual utility and positive impacts on soil fertility and crop yields. Farmers report challenges, such as high initial investment costs, lack of technical knowledge, and limited training, but these are outweighed by perceived benefits like cleaner cooking solutions, reduced labour, and improved household health.

(2) **Private Sector:** The private sector plays a critical role in scaling the pyrolizer by financing its production and distribution. Partnerships with local enterprises ensure cost-effective manufacturing, while collaborations with training institutions provide technical support and user-friendly guides for farmers. Additionally, the private sector facilitates market access for biochar as a soil amendment, offering farmers new revenue opportunities.

(3) **Government:** Government policies and incentives are pivotal for widespread adoption. Subsidies for pyrolizer units, tax benefits for biochar production, and integration of residue management technologies into national agricultural programs can drive uptake. Climate action policies that promote carbon sequestration and soil health improvement further encourage use. Extension services ensure farmers receive adequate training and support, fostering adoption across communities.

(4) **Non-Governmental Organizations (NGOs):** NGOs provide vital technical expertise in biochar application and climate-smart agriculture, bridging the gap between farmers, private enterprises, and government bodies. Their efforts in community engagement foster trust and social acceptance of the technology. NGOs also emphasize the social benefits, particularly for women, by highlighting clean cooking solutions that reduce exposure to harmful smoke and empower women through improved household health and labour efficiency.

Anticipated Impacts

Environmental Impact

The pyrolizer significantly reduces greenhouse gas emissions by eliminating residue burning and promotes long-term carbon sequestration in the soil. It also improves soil fertility, mitigates erosion, and enhances water conservation.

Economic Impact

Farmers experience increased productivity and incomes due to higher crop yields and reduced fertilizer costs. The commercialization of biochar offers additional revenue opportunities, while household fuelwood expenses are lowered.

Social Impact

Health outcomes improve as indoor air pollution is reduced, benefiting women and children most significantly. Cleaner cooking technologies and reduced labour burdens enhance gender equity, contributing to the well-being of rural households.

In conclusion, the Multipurpose Pyrolizer cum Cooker embodies an integrated, climate-smart approach to sustainable agriculture, environmental conservation, and community development. Overcoming barriers such as financial constraints, knowledge gaps, and policy limitations will be key to maximizing its transformative potential in the Himalayan highlands and beyond

Lessons Learned

The Multipurpose Pyrolizer cum Cooker has significantly enhanced productivity for farmers, primarily through biochar application. This sustainable residue management practice has improved soil fertility, nutrient availability, and moisture retention, leading to a 20% yield increase in maize during field trials. The resulting higher incomes and reduced reliance on chemical fertilizers, due to minimized nutrient leaching, highlight the economic value of the technology. Furthermore, the pyrolizer strengthens resilience against climate-induced vulnerabilities. By improving soil structure and water-holding capacity, it equips crops to withstand droughts and erratic rainfall patterns. Over time, the resulting healthier soils bolster the region's capacity to adapt to temperature fluctuations and other stresses associated with climate change. From an environmental perspective, the pyrolizer substantially reduces greenhouse gas emissions by eliminating the need for residue burning, significantly cutting CO_2 and methane releases. Its biochar locks carbon in the soil for extended periods, aiding long-term climate mitigation efforts. Indirect benefits include reduced deforestation and biodiversity conservation due to a decreased reliance on fuelwood. The dual-purpose design of the pyrolizer has also fostered economic and social benefits by creating employment opportunities in its production and distribution, as well as in biochar commercialization. Households benefit from reduced fuelwood expenses, while women, in particular, experience improved health and gender equity due to cleaner cooking solutions.

Cooker cum pyrolizer has decreased indoor air pollution caused by cooking as it is highly efficient and produces less toxic gas with proper ventilation. Women and children will face fewer respiratory problems. Fuel wood collection and social impact on collecting fuel mostly women are involved in it improved it. The extra income generated from the sale of biochar has improved socio-economic conditions.

Despite these advantages, several barriers persist. Financial constraints limit smallholder adoption due to high initial costs, necessitating subsidies or credit schemes. Knowledge gaps regarding pyrolizer use and biochar application hinder widespread benefits. Socio-cultural resistance to new technologies, coupled with limited private sector involvement in financing and market development, poses additional challenges. Furthermore, inadequate policy support in terms of subsidies and alignment with climate action goals restricts integration into mainstream agricultural practices.

Addressing these barriers is essential for unlocking the technology's full potential in the Himalayan highlands.

Recommendations

We have successfully developed a Pyrolizer cum cooker which world's first such technology and has been granted a patent by Indian Patent Office. Our technology has the potential to avert 2,675,340 tons of CO2 annually from the Himalayan Highlands. We have validated and tested this technology in field conditions. Overall carbon and energy footprints have been drastically improved making Himalayan highlands sustainable and climate-friendly hence securing the whole subcontinent because it is affected by Himalayan highlands for water and other crucial resources.

Recommendations

- We successfully developed a Multipurpose pyrolizer cum cooker for carbon-neutral residue management in Himalayan highlands.
- Validation of pyrolizer developed various biochar quality parameters and other carbon and energy balance assessments.
- Field testing of Biochar developed at different temperatures and its evaluation for enhancing the performance of Maize Yields via soil Health enrichment and carbon sequestration.
- Evaluation of water holding capacity and drought mitigation potential of this technology to secure the socio-economic status of Himalayan Highlands.
- Carbon sequestration assessment of technology developed for climate change adaptation and mitigation strategies in Himalayan Highlands.
- The overall well-being of women and the general public through air pollution mitigation and clean and safe household cooking.

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3.5 Case Study 10: Optimisation of Topography and Climate Conditions for Crop Diversification

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Abstract

Himachal Pradesh, located in the Himalayan foothills of northern India, is leveraging its diverse topography and climate to enhance agricultural livelihoods through crop diversification. The Himachal Pradesh Crop Diversification Project aims to transition farmers from subsistence grain farming to high-value vegetable cultivation by promoting sustainable practices tailored to agro-ecological zones. This initiative has introduced innovative techniques, including improved seed and seedling quality, water-saving irrigation methods, and organic farming, alongside training and market linkages. The project has significantly boosted agricultural productivity, strengthened resilience to climate change, and improved household incomes, particularly for women-led Self-Help Groups (SHGs). By addressing challenges such as climate variability, water scarcity, and ecosystem degradation, the project underscores the potential of targeted interventions and stakeholder collaboration to foster sustainable agriculture. The lessons and outcomes offer valuable insights for scaling similar initiatives in highland areas across Asia.

Background

Due to the area's topography at the foot of the Himalayas, farmlands are scattered from 370 m to 2,400m above sea level. The covered area by the project is divided into 3 categories such as Sub-Mountain low hills sub-tropical (Zone-I), Mid-hills sub-humid (Zone-II), and High hills sub-temperate wet (Zone-III).

Even though farmers account for 70% of the workforce, the primary source of income is not from agriculture but from others. Therefore, the main labourers in the field are women. Most of the men are weekend farmers. SHGs (Self Help Groups) are active producers, processors and sellers. There are also the SHG Federation and Farmer’s Association. They work as mass purchasers and providers of agricultural materials and collectors, processors and sellers of produce. Himachal Pradesh has been experiencing the effects of climate change in a number of ways, including:

Rising temperatures: The State's average annual mean temperature has increased by 1.2 °C since 1981-2010, and the maximum temperature has risen by 2.18 °C per century. The number of heatwaves has also been increasing, with more severe heatwaves occurring in the winter and spring. It caused hailstorms and severe damage to fruits and vegetables.

Rainfall: Heavy rainfall can lead to flash floods, erosion, and landslides. Dams in the State can also cause riverine disturbances when they open floodgates without warning.

Ecosystem impact: The glaciers in Himachal Pradesh are melting rapidly due to climate change, which is causing several issues, including water insecurity, landslides, avalanches, floods, glacial lake bursting, etc. The State's unique forests and habitats are vulnerable to changes in temperature and rainfall patterns. The Himalayan ecosystem is also stressed by other factors, such as population growth, mining, and infrastructure development.

Bee deaths: Climate change is causing the deaths of bees, which are important for apple production.

Rationale

Increasing agricultural productivity sustainably

There is an urgent need to increase agricultural productivity sustainably. This is because climate change is expected to continue, and the agricultural population is decreasing yearly. There are various reasons why productivity is low: (i) cultivation is not conducted in proper timing, (ii) quality seeds or seedlings are not adopted, (iii) application of fertilizer is not sufficient, (iv) plant protection measures are not sufficient, etc. In addition, the economy of the State has shown a shift from the agriculture sector to industries and services as the percentage contribution of agriculture in total Gross State Domestic Product has declined from 57.9 per cent in 1950-51 to 9.50 per cent in FY2021-22. The multiple influences of these causes have affected productivity. Long-term measures are expected to be taken to improve productivity.

Enhancing resilience to climate change

Now is the time for agriculture that is resilient to climate change. Since Himachal Pradesh has been experiencing climate change and crop losses in several ways, as I mentioned in the background part. Farmers suffer from (i) rising temperatures, including increased heat waves, thunderstorms, and hailstorms. From 1984 to 2023, Himachal Pradesh experienced 669 heatwaves, (ii) seasonal heavy rainfall and drought caused damage to fields; however, State average rainfall decreased significantly at 95% level for January (-0.61 mm/year), July (-1.83 mm/year), August (-1.49 mm/year) and October (-0.90 mm/year), (iii) ecosystem impact (less snow in winter, melting of permanent glaciers, etc.; The area covered by snow in Himachal Pradesh has decreased by 18.5% between 2019-20 and 2020-21. The snow cover in the lower Sutlej, Ravi, Beas, and Chenab River basins has shrunk by 10.02%. The glaciated area in Himachal Pradesh decreased by 67.84 km^2 per year from 1994 to 2021) affected uncertain water sources.

Proposed Solution

To solve the problem of water scarcity, check dams were provided by the JICA ODA loan project in hilly areas and gravity water distribution channels were used to make it more sustainable. Extension officers gave the farmers the operation and maintenance training, and farmers organised the water users' association and collected the water usage fee for future maintenance costs. In plain areas, the DOA loan project introduced mulch and micro irrigation for water-saving cultivation. In hot and sunny areas, the DOA loan project introduced solar pumps. For water distribution, gravity must be effective even in highland areas in Thailand.

Cutting and grafting techniques were introduced to improve seed and seedling quality. Palampur Agricultural University played an active role in promoting grafting. They could increase their success rate from 5% to 95%. Nurseries in sand were also introduced to make seedlings more drought-tolerant (Figure 28). The nursery condition was improved by using a double tunnel for cold weather and a shade net for hot weather to produce an off-season nursery. By using these techniques, farmers could increase the germination rate from 30-40% to more than 80%. These techniques can be applied to highland areas in Thailand.

Cropping schedules for each climate zone were provided for off-season and exotic vegetable cultivation to maximize farmers' profits. This technique is also useful to highland areas in Thailand to maximize their income. That is a merit of high land area.

Organic fertilizer and organic insect repellent production were promoted to ensure productivity. Since on-time application of fertilizer is indispensable to increase productivity. If the farmers in the highland keep animals, cow dung, pig manure, or chicken drops will become a good source of organic fertilizer. They also have similar vegetation to Himachal Pradesh; therefore, they can produce organic insect repellents.

Lower polytunnels, double tunnels, shade net tunnels, rain shelter tunnels, non-woven sheets (floating cover sheets), and anti-hail nets were introduced for plant protection (Figure 29).

The role of the JICA Technical Cooperation Project is to support the activities of the JICA ODA Loan Project. It had 8 demonstration sites in 5 districts and provided training to DOA staff and ODA loan project staff as TOT at farmer's field and in class. JICA TCP staff compiled guidelines with DOA staff to implement the JICA ODA loan project. As a teaching tool, picture stories were developed by JICA TCP experts. Through TOT, the extension staff have learnt and demonstrated how to use them at the farmer's sites.

JICA TCP compiled 2 booklets titled "Exotic Vegetable Cultivation" and "8 Gems for Your Good Health". The former is for exotic vegetable cultivation techniques and the latter is for using exotic vegetables for health. These two booklets aimed to promote exotic vegetable production and consumption. The promotional event was conducted at school as a play for nutritional education for students, parents, and grandparents to improve food habits and decrease lifestyle diseases such as diabetes, high blood pressure and heart attack. Another event for high-end consumers, like the Rotary Club women's wheel, was also conducted to reduce lifestyle diseases.

To find and connect the market, JICA TCP experts and DOA extension staff visited and surveyed the market's demand. As a result, one company that sold vegetables to the Japanese community purchased exotic and off-season vegetables from project sites. Another shop also purchased exotic and off-season vegetables to sell to the local community in Delhi.

SHG (Self Help Groups) played an active role in production, processing, and sales. Several groups produced local speciality products such as Rhododendron Jam, Chili and lime paste, Dried cherry tomato, Gotukola tea, and Himalayan violet tea. They sold them locally and in Delhi to tourists.

NGOs also supported organic farming. They trained farmers in farm management and how to get organic certificates.

The government changed the extension staff protocol and subsidized polyhouse, micro irrigation systems, and solar pumps.

Figure 28:
Nurseries in sand to make seedlings more dourght-tolerant.

Figure 29:
Lower polytunnels, double tunnels, shade net tunnels, rain shelter tunnels, non-woven sheets and anti-hail nets were introduced for plant protection.

Lessons Learned

(1) Changing cropping patterns is important to produce off-season vegetables to maximise farmers' profits. However, farmers tried to follow traditional cropping patterns. To make them aware of the importance, the market visit was effective.
(2) Managing and maintaining their check dams by themselves and paying water tariffs based on their use are essential skills to be independent of government help. Without discussion and training, it is difficult to pursue. Otherwise, farmers will request continuous financial support.
(3) Conserving forests is effective in reducing GHGs and protecting biodiversity. However, climate change makes it difficult. Population increases and economic activities affect the loss of forests.
(4) Women’s group (SHG) activities increase economic and social benefits. They can contribute to increasing yields and promoting processing and sales on their own. If women can get their own income, they can make decisions at home. There is discrimination towards women still now in the local society. It is vital to make opportunities for women to be on the front.

Challenges and Barriers

(1) Economic merits are enormous by making the Atal tunnel between Manali and Telling in Himachal Pradesh. Before, the road to Lahaul and Spiti was closed for 6 months because of snow at Rothan Path. After the completion of this tunnel, the number of cars increased, accelerating the melting of glaciers and the intrusion of insects before people did not see that area in winter.
(2) JCA Technical Cooperation Project suggested changing the protocol of extension staff to stress extension work. Since the extension work was the last mandate for extension staff, their main work was distributing agricultural materials and subsidies. Even though DOA changed the protocol, the number of extension staff is half of the posts because of a lack of budget.

Recommendations

(1) As mentioned before, farmers in Himachal Pradesh face various types of climate change. It is critical to know how to take countermeasures in advance. For example, using plant protection materials in severe weather is highly recommended. Not only modern technologies but also conventional technologies, such as promoting seed germination in cow dung heap and using groundcover crops instead of plastic mulch, are also practical and effective.
(2) The government needs to provide weather information and sometimes issue warnings in advance. To promote countermeasures for farmers, the government or department should give subsidies to them. Introducing new policies and regulations to preserve the environment and support farming activity.
(3) Researchers need to provide a weather forecast. Based on the forecast, they need to study the next scenario to mitigate climate change. It is also important to study effective countermeasures.
(4) As practitioners, farmers need to introduce modern and conventional methods to improve the situation.
(5) Private sectors such as service providers are important resource persons regarding climate-smart agriculture. They can provide knowledge and techniques. In return, if the government can provide financial support through low-interest rates, favourable taxation etc.

Further Reading

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4. Agricultural Product Quality, Value Chains and Digital Technology

This section focuses on the crucial aspects of agricultural product quality, value chains, and digital technology and how they can be leveraged to enhance the sustainability and competitiveness of farming systems in the face of climate change. Several relevant case studies are included here to illustrate the potential of agricultural product quality, value chains, and digital technology to adapt to climate change and improve farmer's livelihoods.

Maintaining high agricultural product quality and safety standards is essential for several reasons. It safeguards consumer health by ensuring agricultural products are free from contaminants and meet quality standards. Additionally, meeting the quality and safety requirements of domestic and international markets enhances the competitiveness of agricultural products. Improving product quality and safety can lead to value-addition opportunities, allowing farmers to sell their products at premium prices. Finally, sustainable agricultural practices, such as integrated pest management and organic farming, can enhance product quality and safety while minimising environmental impact.

Efficient and sustainable value chains are crucial for connecting farmers to consumers and ensuring that agricultural products reach the market at competitive prices. Strengthening value chains includes value chain mapping, market demand analysis, logistics and infrastructure, and collaboration and partnerships. Value chain mapping involves understanding the flow of products and information throughout the value chain, from production to consumption, to identify bottlenecks and opportunities for improvement. Market demand analysis involves analysing consumer preferences and market trends to guide farmers in producing products that meet demand and command higher prices. Investing in efficient transportation, storage, and processing facilities to reduce post-harvest losses and maintain product quality is also essential. Finally, fostering collaboration among farmers, traders, processors, and other value chain actors can enhance efficiency and market access.

Digital technologies can play a transformative role in improving agricultural value chains' efficiency, transparency, and sustainability. Some notable applications of digital technology include traceability systems, precision agriculture, e-commerce and digital marketing, and big data and artificial intelligence. Traceability systems track agricultural products from farm to consumer, enhancing food safety, reducing fraud, and improving market access. Precision agriculture utilises sensors, drones, and geographic information systems (GIS) to monitor crop health, optimise resource use, and enhance agricultural decision-making. E-commerce and digital marketing connect farmers directly to consumers through online platforms and utilise digital marketing strategies to expand market reach. Big data and artificial intelligence analyse large agricultural datasets to identify trends, predict yields, and optimise farming practices.

Adopting digital technologies in agricultural value chains can lead to numerous benefits, including increased efficiency, enhanced transparency, improved market access, data-driven decision-making, and sustainable agriculture. Increased efficiency streamlines processes, reduces waste, and optimises resource use, lowering production costs and higher profits. Enhanced transparency improves transparency and traceability in the supply chain, building consumer trust and facilitating fair trade practices. Improved market access connects farmers to broader markets, enabling them to sell their products at better prices and access a more comprehensive range of buyers. Data-driven decision-making gives farmers the information they need to make informed decisions about their farming practices, leading to improved yields and reduced risks. Finally, sustainable agriculture is promoted by optimising resource use, reducing the reliance on agrochemicals, and enhancing the resilience of farming systems to climate change.

Ongoing innovation is essential for developing and adapting digital technologies to highland agriculture's specific needs and challenges. This includes investing in research to identify and promote new digital technologies suitable for highland conditions. It also facilitates the transfer of knowledge and technologies from research institutions to farmers and communities. Finally, it is vital to encourage farmer-led innovation and experimentation to adapt digital tools to local contexts.

4.1 Case Study 11: Agricultural Quality and Safety Improvement in Alternate Crops in Nan Province, Thailand

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Abstract

Food safety is essential for protecting public health, ensuring market access, and promoting sustainable development in agriculture and food processing. This study investigates the challenges faced by farmers in adopting Good Agricultural Practices (GAP) and food safety standards, using a structured questionnaire based on the Thai Agricultural Standard (TAS 9001-2013). Key barriers identified include financial constraints, low educational attainment, and limited GAP certification. While over 60% of respondents demonstrated basic knowledge of GAP, gaps in areas such as microbial contamination management, water quality, and traceability persist, particularly among elderly farmers and those with lower education levels.

To address these challenges, the study recommends targeted training programs, financial support, infrastructure investments, and public awareness campaigns. Strengthened regulatory frameworks and participatory guarantee systems are proposed to enhance compliance. Continuous monitoring is crucial to improving food safety practices, public health outcomes, and agricultural resilience, ensuring sustainable and high-quality agricultural production.

Background

Food safety is a fundamental pillar of the agricultural and food processing sectors, forming the basis for safeguarding public health, enabling market access, and fostering sustainable development. Compliance with food safety standards is not just a regulatory obligation for farmers and food processors but also a strategic imperative. Meeting these standards allows stakeholders to align with consumer expectations, mitigate potential risks, and increase the overall value of their products. Farmers bear the primary responsibility for producing safe and high-quality raw materials, while food processors play a vital role in maintaining the integrity of these materials through hygienic and controlled processes. Together, their combined efforts ensure that food products meet both domestic and international quality benchmarks (Grace, 2015b; Powell et al., 2011).

The adoption of robust food safety practices is critical for reducing the incidence of foodborne illnesses, enhancing consumers' quality of life, and enabling access to premium international markets. Nonetheless, many countries face persistent challenges in establishing and enforcing adequate microbiological standards. In industrialized nations, food safety systems strengthen consumer confidence, facilitate global trade, and aim to reduce the prevalence of infectious diseases. Frameworks such as Good Manufacturing Practices (GMP) have been widely acknowledged for their effectiveness in risk management. However, their success is hindered by inconsistent implementation, insufficient training, and inadequate enforcement mechanisms worldwide (Bacs et al., 2007; Kamboj et al., 2020).

Developing nations encounter additional obstacles to implementing food safety standards, including poor sanitation, inadequate access to clean water, and financial constraints. These limitations hinder compliance and expose populations to greater risks of foodborne diseases. Addressing these challenges requires targeted investments in infrastructure, enhanced regulatory frameworks, and capacity-building initiatives, such as training personnel. Such measures are pivotal for reducing foodborne illnesses and facilitating access to international markets. In contrast, developed nations face their own complexities, including intricate regulatory environments and evolving consumer demands, necessitating continuous adaptation to maintain compliance with food safety standards (Forsythe, 2012; Grace, 2015a; Buzby & Roberts, 2009).

Food safety concerns extend beyond public health, intersecting with socio-economic and trade dimensions. High-profile outbreaks and contamination incidents frequently exacerbate consumer fears and drive calls for stricter regulations. Strategic investments in robust food safety frameworks are crucial for enhancing public health, rebuilding consumer trust, and developing resilient food systems capable of addressing future challenges (Mendis & Rajapakse, 2009; Okpala & Korzeniowska, 2023; Owusu-Apenten & Vieira, 2022).

Food safety is an indispensable component of both public health and economic stability. By prioritizing investments in infrastructure, regulatory frameworks, and training, nations can overcome existing challenges and ensure a safe, high-quality food supply while meeting the demands of global markets.

Rationale

The implementation of good hygienic practices in food safety is a fundamental aspect of achieving sustainable production and enhancing value-based supply chains. These practices are integrated across all stages of the food supply chain to ensure the safety and quality of agricultural products. At the farm level, Good Agricultural Practices (GAPs) and Participatory Guarantee Systems (PGS) serve as essential frameworks for maintaining the safety and quality of agricultural commodities. These systems focus on compliance with safety standards and prerequisites for sustainable agricultural production. In the processing phase, Good Manufacturing Practices (GMPs) are implemented to ensure that food products meet safety and quality standards before being distributed to the market.

To evaluate current food safety and on-farm practices, a structured questionnaire was developed using checklists derived from the Thai Agricultural Standard (TAS 9001-2013) for GAP in food crops which consists of the following 8 items: (1) Water quality; (2) Planting area; (3) Pesticides; (4) Pre-harvest quality management; (5) Harvest and postharvest handlings; (6) Holding, moving produce in planting plot, and storage; (7) Personal hygiene; and (8) Record keeping and traceability. In-depth interviews were used as the main method of collecting qualitative data. This instrument facilitated interviews with farmers and food processors, focusing on their basic food safety practices and adherence to GAP standards. The findings from these interviews were instrumental in identifying gaps in knowledge and practices among stakeholders. Subsequently, the data informed the development of targeted training programs aimed at addressing these deficiencies. These training programs were designed to enhance farmers' knowledge in areas such as GAP compliance, on-farm safety practices, and overall food quality management.

This study underscores the critical role of systematic evaluations and capacity-building initiatives in improving food safety practices at farm and processing levels. By addressing identified knowledge gaps, these efforts contribute to the overarching goal of promoting sustainable agricultural production and fostering resilient supply chains.

Proposed Solution

A structured questionnaire was developed to evaluate farmers' knowledge, attitudes, and practices (KAP) regarding good hygiene and food safety, based on the GAP standards for food crops outlined in the Thai Agricultural Standard (TAS 9001-2013) (Figure 30 and 31) The questionnaire was designed to assess multiple dimensions of food safety practices through the following sections:

(1) **Demographic Characteristics**: This section gathered baseline information about the respondents, including age, gender, education, and farming experience.
(2) **Evaluation of Knowledge**: This component assessed farmers' understanding of basic food hygiene and on-farm food safety practices.
(3) **Evaluation of Attitudes**: This section evaluated farmers' perspectives and beliefs regarding food safety and on-farm food safety practices.

(4) **Evaluation of Practices**: This segment assessed the extent to which farmers implemented food safety and on-farm safety practices in their agricultural operations.

Figure 30:
Completing questionnaires by meeting with farmers.

Figure 31:
Completing questionnaires by meeting with farmers.

To ensure the reliability of the instrument, the questionnaire was quantitatively tested using the Kuder-Richardson 20 (KR-20) coefficient, a statistical method appropriate for dichotomous items. The reliability testing provided evidence of the internal consistency and reliability of the instrument for the intended purpose.

The validated questionnaire was subsequently finalized and utilized for data collection among farmers. The data obtained through this instrument is expected to provide insights into current practices and inform targeted interventions to improve food safety knowledge and adherence to GAP standards.

Food safety and the implementation of Good Agricultural Practices (GAP) are critical components in ensuring the sustainability of agricultural production and public health. Despite the availability of frameworks like GAP, many farmers face challenges in adopting and implementing these standards due to various capacity gaps. This essay analyses the results of a survey conducted to identify these gaps among farmers and suggests key areas for intervention.

The demographic analysis of respondents revealed that 84.2% had extensive agricultural experience of more than 12 years. While this level of experience indicates a strong foundation in farming, educational attainment among respondents was low, with 52.6% having only primary-level education. This lack of formal education could impede the understanding and adoption of modern agricultural and food safety practices. Furthermore, the predominant crops in the area were rubber (57.9%) and maize for feed (26.3%), with home-grown vegetables constituting only 5.3% of production. This highlights a focus on non-food crops, which are less directly tied to food safety standards, potentially reducing farmers' motivation to adopt GAP certification.

One of the critical barriers identified was the low rate of GAP certification among farmers. While 52.6% of respondents had participated in GAP training programs, only 10.5% were GAP-certified. The primary reasons cited for this discrepancy were financial constraints (78.9%) and the dominance of non-food crops in their production systems. Certification remains a key driver of compliance with food safety practices, as certified farmers were significantly more likely to implement these practices compared to their non-certified counterparts.

The survey also assessed farmers' knowledge, attitudes, and practices (KAP) related to food safety and GAP. Over 60% of respondents demonstrated a basic understanding of food safety and GAP standards. However, gaps persisted in critical areas, such as managing microbial contamination, ensuring water quality, and maintaining proper records and traceability. These knowledge deficits highlight the need for targeted training programs to address specific challenges in food safety implementation.

Demographic factors played a significant role in shaping farmers' knowledge, attitudes, and practices. Elderly farmers were found to have lower knowledge levels and more negative attitudes toward GAP implementation, suggesting the need for tailored interventions for this group. Education was positively correlated with knowledge acquisition but did not significantly influence attitudes or practices. Interestingly, GAP training programs were effective in improving farmers' attitudes but did not substantially enhance their knowledge levels. This finding underscores the importance of complementing training with practical demonstrations and hands-on support. Most importantly, the study revealed that only formal GAP certification led to the consistent adoption of food safety practices, emphasizing the critical role of certification in bridging the gap between knowledge and practice.

Lessons Learned

The findings from this study highlight the multifaceted challenges faced by farmers in adopting food safety standards and GAP. While training and education are essential, financial support and incentives are equally critical to overcoming barriers to certification. Future interventions should focus on providing accessible certification processes, enhancing training programs with practical components, and addressing specific knowledge deficits such as microbial contamination management and water quality improvement. Additionally, tailored support for elderly farmers and those with lower educational attainment can further bridge the gaps in knowledge and practice.

In conclusion, the implementation of food safety practices and GAP standards requires a comprehensive approach that addresses both systemic and individual challenges. By investing in targeted training, certification processes, and tailored interventions, stakeholders can empower farmers to adopt and implement food safety standards effectively. These efforts are essential not only for improving the quality and safety of agricultural products but also for ensuring the sustainability and resilience of agricultural systems in the long term.

Recommendations

The recommendation is based on the implementation and provides practical insights.

Establish Comprehensive Training Programs

Implementation: Develop targeted training modules covering microbial contamination management, water quality assurance, and traceability systems.

Strategy: Use practical demonstrations, on-farm workshops, and digital learning tools to improve knowledge retention. Collaborate with agricultural extension services and universities to scale training efforts.

Increase Accessibility to GAP Certification

Implementation: Simplify certification processes and offer financial support through subsidies or low-interest loans.

Strategy: Partner with financial institutions and government agencies to develop farmer-friendly funding models. Create step-by-step guides to reduce bureaucratic barriers.

Build Capacity Among Extension Workers and Trainers

Implementation: Provide specialized training to extension workers to effectively transfer knowledge on food safety and GAP.

Strategy: Establish a train-the-trainer program to expand outreach. Integrate mobile and online platforms to ensure continuous learning.

Invest in Agricultural Infrastructure

Implementation: Develop clean water systems, sanitation facilities, and improved storage solutions.

Strategy: Leverage public-private partnerships to fund infrastructure improvements. Provide small-scale grants to support local-level initiatives.

Develop Tailored Interventions for Vulnerable Groups

Implementation: Use simplified materials and community-based approaches to support elderly farmers and those with lower educational attainment.

Strategy: Create visual guides, audio materials, and peer-support groups to facilitate knowledge transfer. Engage local leaders to promote adoption.

Strengthening Regulatory Frameworks and Monitoring Mechanisms

Implementation: Enhance enforcement of GAP and GMP through regular inspections and compliance incentives.

Strategy: Develop digital reporting tools for real-time monitoring. Establish risk-based auditing systems to prioritize high-risk areas.

Promote Participatory Guarantee Systems (PGS)

Implementation: Encourage farmers to adopt a peer-reviewed certification process as a cost-effective alternative.

Strategy: Train farmer cooperatives on PGS principles and provide resources to set up self-monitoring systems.

Launch Public Awareness Campaigns on GAP-Certified Products

Implementation: Educate consumers on the benefits of GAP-certified food to increase demand.

Strategy: Use social media, local markets, and community events to spread awareness. Collaborate with retailers to highlight GAP-certified products.

Establish Continuous Monitoring Systems

Implementation: Implement data-driven tracking of food safety practices and outcomes.

Strategy: Develop key performance indicators (KPIs) and use digital dashboards to assess progress. Conduct periodic evaluations to refine interventions.

Implementing these strategies will enhance food safety, improve agricultural resilience, and drive widespread adoption of Good Agricultural Practices. A coordinated approach involving training, infrastructure investment, regulatory enforcement, and consumer awareness will ensure long-term sustainability and impact.

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4.2 Case Study 12: Harnessing Digital Innovation to Elevate Food Safety and Quality: Insights from Thailand's Durian Export Industry

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Abstract

This case study examines the role of digital innovation in enhancing food safety and quality management in Thailand's durian export sector. It evaluates traceability initiatives within the Greater Mekong Subregion Sustainable Agriculture and Food Security Program (GMS SASRP), highlighting the integration of GS1 standards, RFID, and QR code-based traceability systems to improve supply chain transparency. These technologies ensure compliance with Good Agricultural Practices (GAP) and facilitate seamless cross-border trade. The pilot demonstration of durian traceability from Thailand to China showcased the effectiveness of collaboration between the Thailand National Science and Technology Development Agency (NSTDA), GS1 China, and private sector actors in addressing food safety concerns. Findings underscore the potential for digital solutions to advance climate-smart agriculture by mitigating climate-related risks and enhancing supply chain resilience in response to erratic rainfall and rising temperatures.

Background

Geographical and Socio-Economic Context

Thailand, often referred to as the “Durian Capital of the World,” is a major global exporter of durians, with the People’s Republic of China (PRC) being its largest market. The country’s tropical climate, fertile soils, and superior durian varieties, particularly the prized Monthong, position Thailand as a dominant force in global durian production. The southern provinces of Chanthaburi and Chumphon serve as key production hubs, offering ideal growing conditions for premium durians (Burapha University Durian Value Chain Baseline Study, 2023).

Durian cultivation plays a significant role in Thailand’s agricultural economy, providing substantial income for rural communities. The industry is primarily composed of smallholder farmers, but private sector involvement in packing houses, processing, and exports has been growing in response to surging Chinese demand. However, supply chain fragmentation and weak traceability mechanisms limit market efficiency, food safety compliance, and transparency. Moreover, long-distance transportation and storage challenges underscore the need to uphold food safety and quality standards.

Climate Challenges and Supply Chain Vulnerabilities

The Thai durian industry faces increasing climate variability, which threatens both production and supply chain stability. Key challenges include:

- **Erratic Rainfall Patterns:** Unpredictable rain affects flowering and fruit development, leading to inconsistent yields.
- **Rising Temperatures:** Higher temperatures can shorten the growth cycle, impact fruit quality, and increase post-harvest losses.
- **Soil Degradation:** Intensive farming practices contribute to soil nutrient depletion, affecting long-term sustainability.
- **Prolonged Droughts:** Water shortages can reduce durian productivity and increase vulnerability to pests and diseases.

In addition to climate risks, inadequate logistics infrastructure worsens post-harvest losses. Weak cold chain logistics contribute to food spoilage during transportation, raising greenhouse gas emissions and reducing export-quality durians (NSTDA Cross-Border Traceability Report, 2023).

These challenges emphasize the urgent need for climate-smart agriculture practices, supply chain innovations, and efficient traceability systems to enhance resilience and market competitiveness.

Rationale

This case study addresses the three pillars of Climate-Smart Agriculture (CSA): increasing agricultural productivity sustainably, enhancing resilience to climate change, and reducing greenhouse gas (GHG) emissions.

Increasing Agricultural Productivity Sustainably

Digital traceability systems, such as GS1 Electronic Product Code Information Service (EPCIS) standards, RFID tags, and QR codes, enhanced supply chain efficiency and compliance with Good Agricultural Practices (GAP) standards. These technologies improved product monitoring from the orchard to export, reducing losses from mismanagement and non-compliance (TA 9916 Joint Technical Report, 2024). Standardized documentation can help minimize post-harvest losses, optimize handling, and ensure consistent quality for premium markets. This can lead to reduced waste and higher productivity, enabling farmers and exporters to meet stringent international requirements while securing better returns (Burapha University Durian Value Chain Baseline Study, 2024).

Enhancing Resilience to Climate Change

Durian trade faces climate risks such as erratic rainfall, rising temperatures, and extreme weather events. Digital tools like RFID and QR codes can enable real-time monitoring of temperature and humidity during transport, ensuring optimal conditions for maintaining quality. This real-time data tracking (and tracking of sustainable data attributes) can empower stakeholders to address climate-related risks, reducing spoilage and enhancing supply chain resilience. Compliance with PRC import standards was also supported through improved handling and monitoring.

Reducing Greenhouse Gas Emissions

The pilot streamlined logistics, reducing redundancies and delays while decreasing the reliance on physical paperwork through digital documentation, including e-phyto systems (ADB GMS CASP II Strategic Program, 2011). Efficient handling and improved transport have the potential to reduce energy use, waste, and emissions. By ensuring fewer rejections and spoilage, fewer resources such as water, fertilizers, and energy were wasted on produce that would otherwise be discarded.

This initiative demonstrated the value of digital innovation in addressing climate-smart goals. By improving productivity, enhancing resilience, and reducing emissions, the initiative provides a replicable model for other high-value crops and regions across the GMS. It underscores the role of digital transformation in advancing sustainable agricultural practices.

Proposed Solution

The cross-border pilot demonstration between Thailand and China under the GMS SASFP funded under ADB Technical Assistance 9916, introduced innovative climate-smart practices and digital technologies to enhance food safety, quality, and market access. These solutions addressed key challenges in agricultural supply chains and demonstrated the value of collaboration among farmers, private sector stakeholders, government agencies, and development partners. The digital innovations and stakeholder collaboration demonstrated in this pilot offer a replicable model for scaling similar practices across the GMS. By addressing challenges in traceability, compliance, and logistics, the initiative strengthened food safety and quality systems while advancing regional integration and market access. These efforts underscore the transformative potential of digital technologies in building sustainable, climate-resilient agricultural systems.

Climate-Smart Practices and Digital Technologies Implemented

The pilot leveraged digital traceability tools to improve supply chain efficiency and compliance with export standards. These solutions were vital in ensuring transparency and mitigating risks in cross-border trade:

RFID and QR Code Technology

RFID (Radio-Frequency Identification) tags and QR codes were integrated into the supply chain to track durians from orchards to their final destinations in China. These technologies enabled real-time monitoring of shipments, reducing risks of spoilage and quality degradation during transportation. Farmers, packing houses, and exporters could ensure end-to-end traceability while meeting consumer demands for transparency (NSTDA Cross-Border Traceability Report, 2023) (Figure 32 and Figure 33).

GS1 EPCIS Standards

GS1's Electronic Product Code Information Services (EPCIS) served as the backbone for seamless data exchange between Thailand and PRC stakeholders. The adoption of these global standards facilitated compliance with PRC import regulations, ensuring that durian shipments met both food safety and quality requirements. This interoperability between systems also enhanced supply chain transparency, fostering trust among exporters and PRC importers (TA 9916 Joint Technical Report, 2024).

Real-Time Monitoring with Data Loggers

Temperature and humidity data loggers were used during transport to monitor environmental conditions and maintain product freshness. This innovation directly addressed quality concerns raised by PRC importers and ensured that the durians reached their destination in premium condition. The integration of real-time monitoring minimized risks associated with spoilage and delays, increasing the reliability of the supply chain (Burapha University Durian Value Chain Study, 2024).

Digital Record-Keeping Systems

Farmers and packing houses were trained to adopt digital systems for recording cultivation practices, inventory, and shipments. These systems improved compliance with GAP standards and streamlined the export documentation process, reducing administrative inefficiencies and enhancing readiness for international trade.

Relevance to the Highland Context

Regions like Chanthaburi, Thailand, which feature mountainous terrain and fragmented agricultural systems, face logistical challenges in ensuring consistent product quality. The traceability systems deployed in the pilot addressed these challenges by consolidating fragmented data across the supply chain. Digital monitoring allowed stakeholders to identify and address inefficiencies in real-time, ensuring that durians met export standards despite logistical constraints. The integration of climate-smart technologies into the highland context also supported sustainable agricultural practices, ensuring that farmers in such regions could access high-value export markets.

Role of Stakeholders

Farmers were responsible for meeting GAP standards and adopting traceability practices—and this was the biggest bottleneck point under the pilot implementation because there was major resistance to changing the status quo and current way of working.

The private sector, including packing houses and exporters, played a critical role in adopting digital technologies. Packing houses collaborated with the National Science and Technology Development Agency (NSTDA), GS1 Thailand and GS1 China to adapt global standards to local contexts. Close collaboration was needed with PRC importers to ensure compliance with food safety and quality standards. The private sector also invested in logistics infrastructure to improve supply chain efficiency and reduce carbon emissions (NSTDA Cross-Border Traceability Report, 2023).

Government support was essential in aligning policies and incentivizing stakeholder participation. The NSTDA served as the technical implementing partner and covered half of the (in-kind) pilot implementation costs. The Thailand Ministry of Agriculture and Cooperatives and the Ministry of Agriculture and Rural Affairs (MARA) facilitated cross-border collaboration. The success of the pilot was contingent upon strong government support since they played an important role in integrating global traceability standards with national systems to ensure regulatory compliance and facilitate seamless trade with the PRC (TA 9916 Joint Technical Report, 2024).

Development partners such as the TA 9916 Consultants deployed under the Asian Development Bank (ADB) provided technical expertise, in collaboration with other development partners like the Mekong Instituted, GIZ. These organizations ensured alignment with regional goals, including the Siem Reap Strategy. Their involvement is essential in bridging gaps in institutional capacity, promoting policy harmonization, and supporting the scalability of digital traceability solutions across the Greater Mekong Subregion.

Non-Governmental Organizations (NGOs) and Community Engagement. NGOs like Durio Innovation and local Durian Cooperatives facilitated grassroots engagement and supported farmers in understanding pilot mechanisms. They supported raising awareness about the importance of traceability and digital innovations.

Figure 32:
Engagement with Durian farmers.

Figure 33:
The produce can be traced through an app.

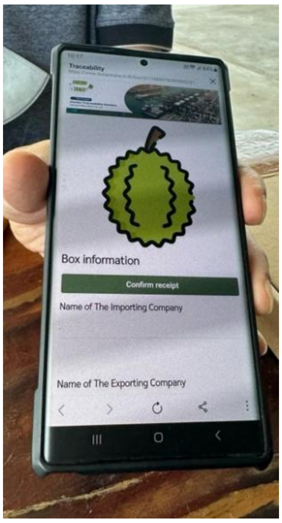

Figure 34:
QR codes on the trucks allowed real time monitoring during transport.

Lessons Learned

The pilot provided valuable insights into improving food safety, quality, and market access while addressing challenges in digital innovation implementation. The pilot demonstrated the potential of digital traceability systems to enhance food safety, market access, and sustainability. Addressing challenges like knowledge gaps, regulatory discrepancies, and infrastructure constraints will be crucial for scaling this model across other GMS value chains.

Resilience

The system enhanced supply chain resilience by mitigating risks through real-time monitoring of environmental conditions like temperature and humidity. Data-driven decisions minimized the impact of spoilage during transportation, ensuring consistent product quality and supply to PRC markets. Farmers adapted to climate variability, better managing risks such as unseasonal rain and high temperatures (TA 9916 Joint Technical Report, 2024).

Environmental Benefits

By reducing rejected shipments and food waste, the pilot promoted sustainability. Streamlined logistics lowered energy consumption and greenhouse gas emissions, aligning with Thailand's sustainability goals. Adherence to GAP standards can also encourage environmentally friendly farming practices, such as reduced pesticide use and better soil management.

Challenges and Barriers

Initial resistance to adopting digital tools and limited technical expertise among stakeholders slowed implementation. Misaligned regulations and regulatory bottlenecks between Thailand and the PRC also created delays.

Recommendations

The pilot project demonstrates significant potential for scaling digital traceability solutions across the GMS region. The following recommendations aim to address key challenges, including knowledge gaps, regulatory discrepancies, and capacity constraints, to expand the impact on food safety, quality, and market access while promoting regional integration and sustainability:

Scaling Traceability Systems

The success of the durian pilot provides a strong foundation for expanding traceability systems to other high-value commodities (e.g., mangoes, dragon fruit) and additional geographical areas. To enhance adoption and address knowledge gaps, the following measures should be implemented:

Consumer-Facing Features: Incorporate QR codes linked to verified product information, including origin, quality certifications (e.g., GAP, GMP, HACCP), and sustainability practices. This will improve consumer trust, leading to higher demand for GMS agricultural exports.

Real-Time Data Integration: Strengthen farm-to-market digital linkages by integrating RFID, blockchain, and cloud-based platforms for seamless data sharing across the supply chain.

Importer Feedback Mechanisms: Establish importer-driven traceability feedback loops that allow Chinese buyers and regulators to report concerns in real-time, improving compliance and market responsiveness.

Smallholder Farmer Inclusion: Ensure affordable and accessible digital traceability tools for smallholders to reduce barriers to adoption.

Policy Harmonization

To streamline cross-border trade, GMS countries should align food safety and traceability standards through collaborative platforms such as the GMS Working Group on Agriculture (GMS WGA) and regional trade agreements. Key policy recommendations include:

Mutual Recognition Agreements (MRAs): Establish mutual recognition of certification systems (e.g., GAP, GMP, HACCP) to ease regulatory burdens for exporters.

Harmonized Digital Traceability Protocols: Develop unified digital traceability frameworks that ensure data interoperability across GMS supply chains.

Regulatory Coordination with PRC Authorities: Strengthen regulatory alignment with China's General Administration of Customs (GACC) to facilitate market access and simplify compliance requirements.

Policy Incentives for Traceability Adoption: Governments should provide regulatory incentives for agribusinesses investing in climate-smart and digital traceability solutions (e.g., fast-tracking of export approvals for compliant businesses).

Capacity Building

Capacity-building efforts should bridge knowledge gaps and ensure effective implementation of traceability systems. The following actions are recommended:

Farmer Training on Digital Tools: Provide training programs for smallholder farmers on using QR code tagging, mobile apps, and farm record-keeping systems to increase digital adoption rates.

Exporter & Regulator Competency Development: Conduct regional workshops to improve exporters' understanding of international traceability standards and ensure regulators are equipped to verify compliance.

Technical Support for SMEs: Establish traceability incubators to assist small and medium-sized enterprises (SMEs) in integrating digital solutions without prohibitive costs.

Private Sector Engagement

Encouraging private sector participation is essential for scaling innovations in traceability. Recommended actions include:

Incentives for Agribusiness Investment: Governments should offer tax breaks, subsidies, or grants to exporters, processors, and technology providers that implement traceability systems aligned with climate-smart agriculture (CSA) principles.

Public-Private Partnerships (PPPs): Foster partnerships between tech providers, logistics firms, and certification agencies to drive the development of scalable digital traceability models.

E-Commerce Integration: Collaborate with Chinese e-commerce giants (e.g., Tmall, JD.com) to establish traceability-linked marketing campaigns, improving market differentiation for GMS products.

Regional Collaboration

Strengthening cross-border partnerships will promote wider adoption of traceability systems and ensure compliance with evolving market demands. The following initiatives should be prioritized:

GMS-PRC Traceability Alignment: Engage PRC importers, retailers, and regulators to synchronize traceability requirements with China's import protocols.

Joint Research & Development (R&D) Initiatives: Establish collaborative R&D programs with regional universities and agricultural institutes to develop AI-driven traceability tools.

Regional Digital Trade Platforms: Expand participation in digital trade facilitation platforms under ASEAN and APEC initiatives, improving GMS-wide trade integration.

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4.3 Case Study 13: Practical Digital Solutions for Smallholders: Linking Farm Management from Planting to Post-Harvest for Enhanced Traceability and Sustainability

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Abstract

Highland farmers in Nan Province, Thailand, are transitioning from maize monoculture to organic perennial cropping to address rising production costs, soil degradation, and climate risks. This case study demonstrates the effectiveness of digital solutions, including the integrated FarmAI platform, to enhance farm management, traceability, and sustainability. By digitizing 34 farmer plots, the project provided tools for monitoring soil health, managing crops, and connecting production to end-users through QR codes linked to traceability systems. Using drones, Near Infrared (NIR) scanners and real-time data systems enabled farmers to optimize resource use, improve soil nutrition, and reduce environmental impact. The initiative also facilitated compliance with organic certification standards, unlocking access to premium markets for essential oils. Despite challenges such as limited awareness, infrastructure gaps, and policy constraints, the project underscores the potential of digital technologies to transform highland agriculture, offering a scalable model for sustainable farming practices in similar regions.

Background

While farmers have historically adapted to uncertainty, climate change is introducing more severe and frequent challenges—seasonal shifts, prolonged droughts, and increased microclimate variability. Over the past 30 years, Nan has experienced a steady rise in temperatures and increasingly unpredictable rainfall patterns. These changes are significantly affecting crop growth, causing increased crop stress, and threatening farmer productivity and livelihoods.

Unsustainable farming practices and the over-exploitation of natural resources, mainly through monoculture maize production, have further led to severe soil degradation and declining productivity in Nan. The income-to-debt ratio for farming households is projected to reach 0.89 by 2032, intensifying both the economic pressure on families and the environmental strain on the region.

Perennial crops such as lemongrass require less labour and tilling, potentially improving soil health. Its oil extraction provides farmers with an alternative income source. Essential oils from Nan fetch significantly higher market prices than raw herbs, with raw lemongrass selling for THB 5 to 10 per kilogram, while its essential oil can reach prices as high as THB 5,000 per kilogram.

Certified organic products allow access to premium markets with higher prices and consumer demand driven by health-conscious preferences, potentially increasing farmer incomes. Certification also supports long-term environmental sustainability through improved soil health, water conservation, and biodiversity.

Despite these opportunities, farmers in Nan face challenges in adopting organic practices, including limited access to tools for record-keeping and reliable information for compliance. Manual documentation and lack of real-time data hinder efficiency and traceability.

Collaborative efforts involving buyers, extension services, and certification agencies are essential to overcome these barriers. Leveraging digital technologies for farm management and supply chain traceability will enable stakeholders to support sustainable and equitable agricultural systems in the highlands.

Rationale

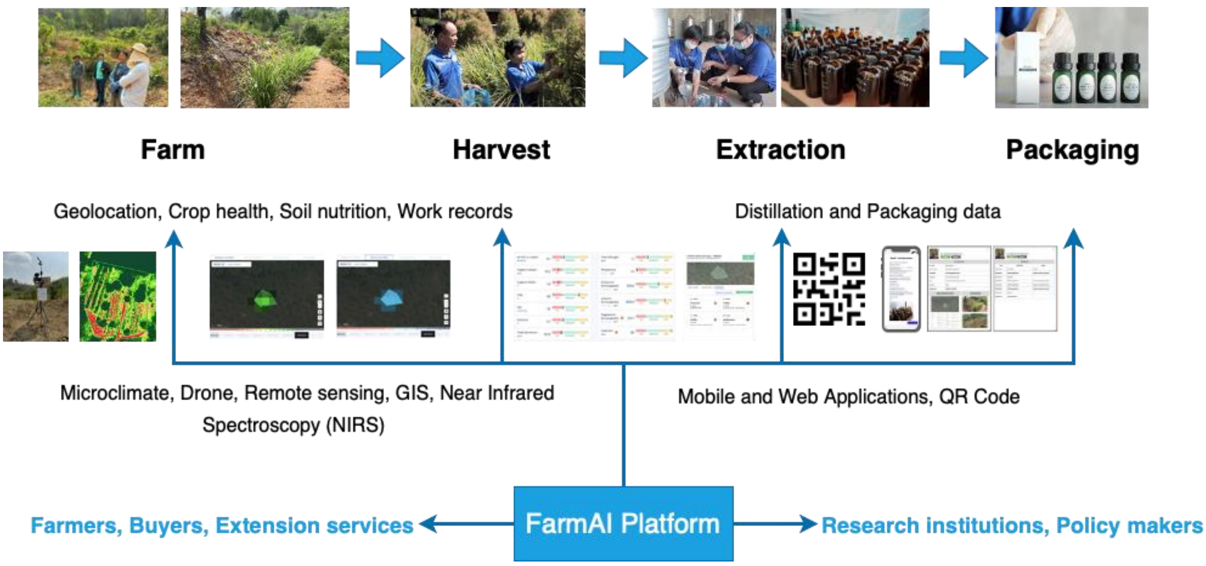
Digital technologies present significant opportunities for improving farm management, particularly for highland farmers, while enhancing traceability throughout the supply chain. Using smartphones, remote-sensing, IoT, cloud computing, and other digital tools is a key enabler in addressing the barriers to adopting traceability for different stakeholders in the highlands. It can help farmers record management practices with greater accuracy and efficiency. The transparency ensures optimal growing conditions are met, reducing production costs and improving efficiency and compliance. For extension service providers and research institutes, precise farm-level data supports expanded outreach and deeper engagement with farmers through tailored recommendations and services. For buyers and certification agencies, transparent and verifiable farmer products ensure compliance with quality standards. Governments and other development sector stakeholders can leverage data to develop evidence-based programs and policies to improve public service delivery and foster equitable and resilient highland agriculture systems.

Proposed Solution

Digitizing the essential oil production supply chain

The project demonstrated a system for recording essential oil production, linked to a farm management system (FarmAI) to accurately trace the source of the raw products, promoting full transparency (Figure 35).

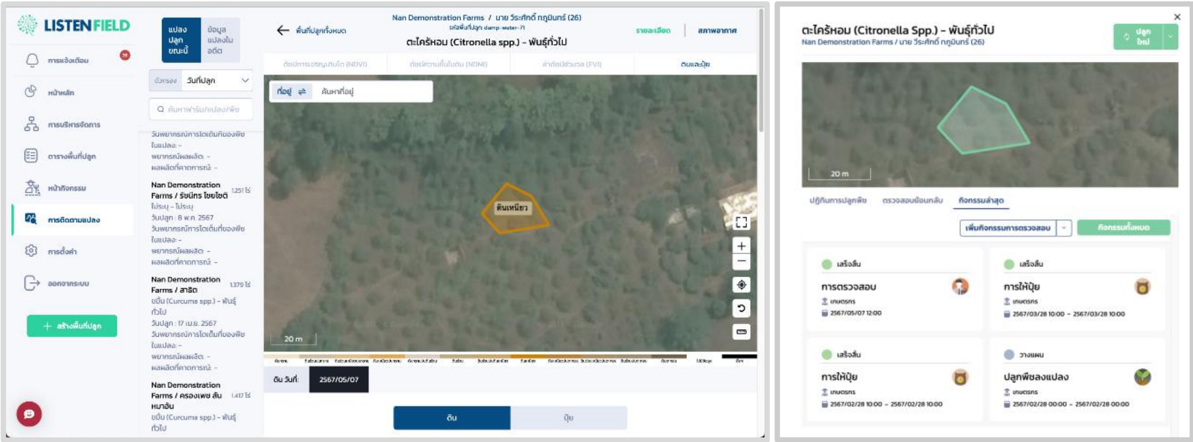
Figure 35:
Utilizing various technologies to improve the visibility of farm and distillation operations.



Stakeholders

(1) **Farmers**: Record farm management practices through the mobile application.
(2) **Local agriculture extension**: Access a web dashboard to provide agricultural advice to farmers.
(3) **Technology Provider (ListenField)**: Provide and train the users on the digital platform (FarmAI).
(4) **Buyers, Certification Agencies**: Evaluate the relevance of the information provided by the digital platform (FarmAI).

Figure 36:
Field polygon and farming activities of a Citronella farmer.



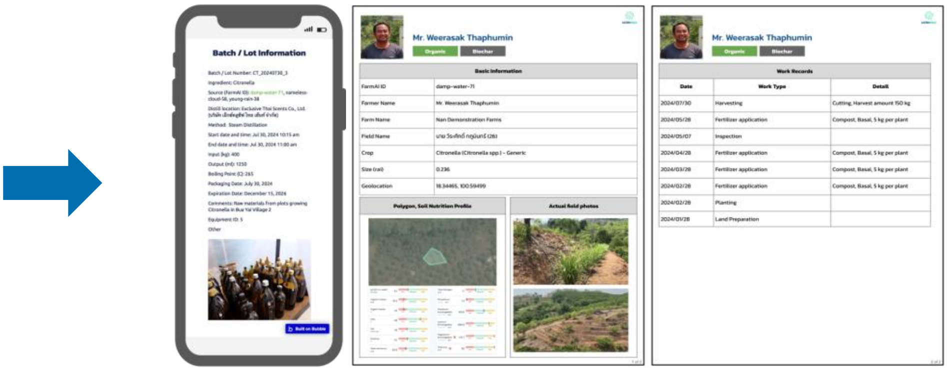
Digital Farm-level Data

Individual farm details such as field polygons, crop varieties, planting dates, and management practices, soil nutrition were digitized, providing information on where the essential oil came from, who grew it, and the conditions under which it was grown and harvested (Figure 36). 34 out of 37 members of the farmer enterprise have already registered their data, subject to monitoring for organic and safety certifications in the future.

QR Codes for Packaging

A QR code was generated that links to the Batch / Lot Information and source farms. This allows farmers to communicate their practices directly to consumers, building trust (Figure 37). In the future, the enterprise may explore using GS1-compliant QR codes, which is a global standard for storing and sharing product information.

Figure 37:
Customer point of view. A report on a specific batch (right) links its raw material to a specific farm (left). The two are linked by the Farm's ID.



Capacity Building

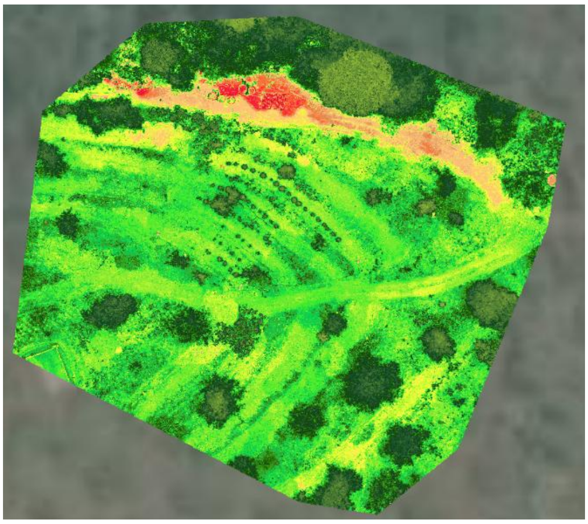
From May 8-9, 2024, ListenField organized various demonstrations in Bua Yai to increase the farming community's exposure to various precision farming technologies—Drone imaging for plant health monitoring, Traditional and modern soil nutrition analysis techniques (Wet Laboratory, Basic Test Kit, Near-Infrared), and Digital platforms for farm management and traceability.

The demonstrations emphasized how recent advancements in precision farming technologies can support traceability efforts and regenerative farming at scale, which can benefit farmer livelihoods. It also emphasized how recent scientific studies have enhanced our understanding of soil dynamics. The goal was to educate farmers and help them explore the practical application of these technologies in their agriculture operations.

Drone imaging for plant health monitoring

ListenField, in collaboration with Kubota Research and Development Asia (KRDA), demonstrated multispectral drone imaging to the farmers (Figure 38). Farmers were briefed on how drones can be utilized for early crop stress detection and nutrient assessment in soil and plants, enabling optimal fertilizer and water use.

Figure 38:
Drone image collection by ListenField in collaboration with Kubota Research and Development Asia (KRDA).



Traditional and modern soil nutrition analysis techniques

ListenField, a recognized expert in soil nutrition analysis, demonstrated both traditional and advanced soil nutrition analysis methods to farmers and agriculture extension staff (Figure 39). Traditional approaches included wet laboratory testing and basic soil test kits provided by the Land Development Department (LDD), offering familiar yet essential tools for soil health assessment.

Figure 39:
Demonstrating traditional and modern soil nutrition assessment to farmers.

ListenField also introduced a portable handheld device that uses Near Infrared (NIR) for on-site soil analysis. The device can quantify soil nutrient levels (e.g., nitrogen) in minutes, empowering farmers with real-time data, and enabling them to make better decisions to improve soil nutrition and yields. The introduction of rapid soil testing devices aligns with the local agriculture extension's ongoing efforts to support highland farmers in improving crop yields and sustainability.

Digital platforms for farm management and traceability

Following the initial training session on digital platforms last April 2023, training sessions on May 8-9, 2024 were held at the community centre to educate farmers on using digital platforms for farm management and traceability. 12 Farmers, 2 Processing facility (Distillation) staff, and 3 Agriculture extension staff attended in person. 2 representatives from buyer organizations were interviewed via LINE to obtain their impressions and feedback on the digital platform (Figure 40 and Figure 41).

Figure 40:
Training District Agricultural Extension Officers on web dashboards for farmer monitoring.

Figure 41:
Training on mobile application for farm digitization on May 8, 2024.

Lessons Learned

Handheld Near-Infrared (NIR) soil nutrition measurement devices may be a practical solution for improving soil data's spatial and temporal resolution in the highlands. NIR technology's ease of use, portability, and cost-effectiveness offer a useful solution for soil mapping and improving soil health in highland regions. Unlike traditional methods, NIR only requires air-dried and ground samples, which reduces the need for specialized technical skills in sample preparation, making the technology more accessible to local communities. Although individual measurements may be less precise, the increased frequency of data collection facilitates continuous monitoring. This empowers farmers to make timely adjustments to their practices, helping to reduce excessive fertilizer use and minimize environmental impact.

Satellite is a convenient tool for plant health monitoring. Drone images can reveal phenomena invisible from satellite images, such as in-field plant health variability. However, highland plots are typically small and dispersed, making drone surveys less cost-effective due to their limited battery life and operational range. Satellites offer broader coverage in a single image and can process data automatically for agronomists at nearly half the cost (through online platforms such as FarmAI). Satellites also enable survey teams to optimize available resources by directing personnel on a per-need basis toward high-risk areas (Figure 42).

Microclimate station data could be an important tool to aid efficient farm operations. The considerable differences in rainfall data between local and regional stations (see Figure 43) highlight the critical need for accurate, localized weather information. Initial comparisons show that data from the Thai Meteorological Department (TMD) often fail to accurately represent actual rainfall patterns. Investing in weather instruments to better capture local weather is strongly recommended to help farmers make more informed decisions on when to plant or harvest.

Figure 42:
Unlike drones, satellite image data can be continuously collected without traveling to the fields.

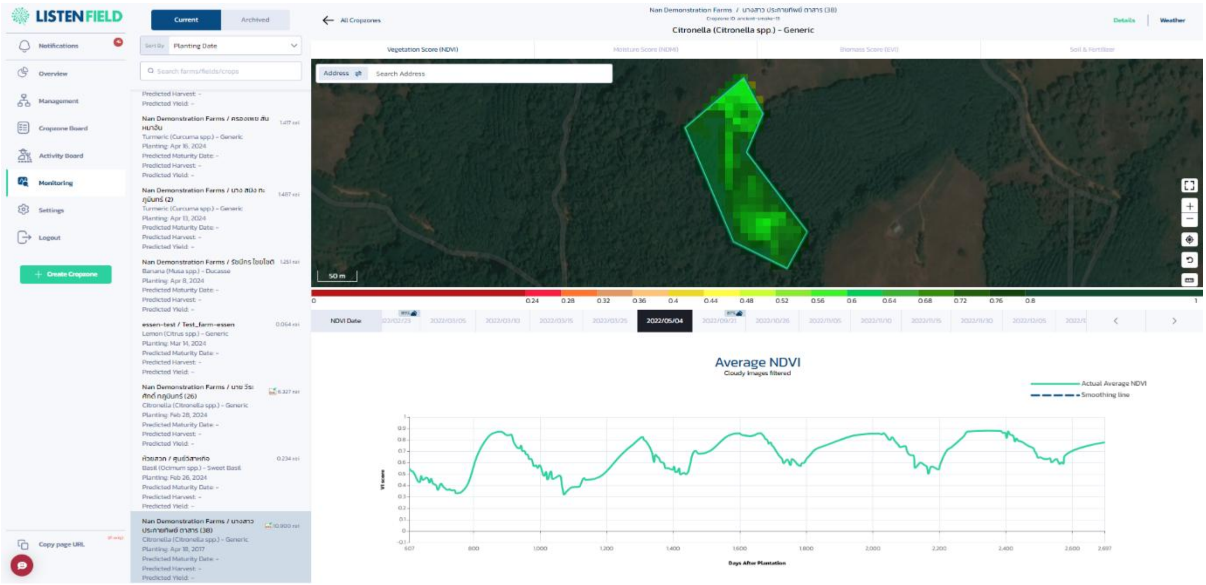
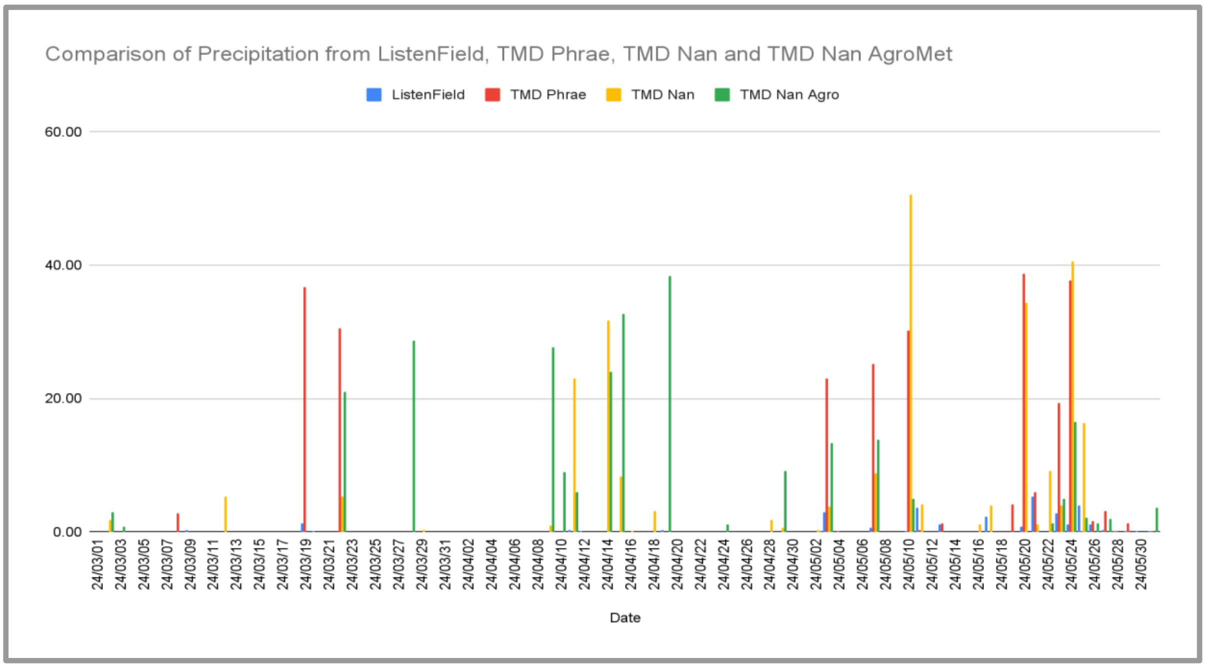


Figure 43:
Daily precipitation was recorded for March to May 2024. Data from TMD stations overreported rainfall, which could affect decision-making. Precise microclimate readings are needed.



Recommendations

Prioritize stakeholder engagement for continuous improvement and trust-building.

- From project inception to completion, identify and involve key stakeholders, including farmers, district-level extension services, and buyers.
- Establish open communication channels to facilitate knowledge sharing and collaboration among stakeholders.
- Conduct regular meetings and workshops to gather input, address concerns, and maintain strong relationships.

Ensure project continuation to allow sufficient time for stakeholders to utilize the technology and see its benefits fully.

- Secure financial support to sustain the project over a meaningful period, allowing communities to experience and benefit from the implemented technologies fully. This will provide enough time for stakeholders to see tangible results and fully integrate the solutions into their operations.
- Implement a robust monitoring and evaluation framework to gather data and measure project impacts. This will help track progress, assess outcomes, and ensure that the solutions continue to meet the needs of stakeholders.

Foster a collaborative and innovative ecosystem.

- Create a supportive ecosystem that encourages collaboration and innovation among stakeholders.
- Develop strategic partnerships with local organizations, NGOs, and research institutions to leverage expertise and resources, which enhance reach and impact and provide additional support for community development.

Identify and empower local leaders who can champion sustainable farming practices and new technologies and drive change within their communities.

- Offer targeted leadership development programs to enhance the skills and knowledge of community leaders. This will ensure they are well-equipped to lead initiatives and sustain project impacts over time.
- Foster a leadership culture by encouraging leaders to act as role models for sustainable development. Their advocacy and example will inspire others in the community to adopt and promote sustainable practices, ensuring long-term success and scalability.

Further Reading

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(9) Barry, R. G. (2008). Mountain Weather and Climate. Cambridge University Press.
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4.4 Case Study 14: Enhancing Traceability and Authenticity of Sindhuli Junar through Blockchain Technology, Nepal

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Abstract

This case study explores the integration of blockchain technology and the KARESA software to enhance traceability and branding for Sindhuli's sweet oranges (Junar). The initiative addressed critical challenges such as product authenticity, post-harvest losses, and market inefficiencies. Through collaboration with Green Growth (Green Growth focuses on the T.E.A. Strategy on driving sustainability and community empowerment by integrating efforts in Tourism, Energy, and Agriculture. Each focus area works cohesively to address global challenges while fostering local impact.) and local cooperatives, a transparent supply chain was established, enabling consumers to verify the origin, quality, and journey of Junar via QR codes. The project also calculated food miles and carbon footprints to support sustainability goals. Farmers benefited from better market access, higher incomes, and reduced wastage, while consumers gained confidence in the authenticity of the produce. The project highlights the role of multi-stakeholder engagement—including farmers, private-sector actors, cooperatives, and government agencies—in promoting climate-smart agriculture. Lessons learned from this pilot demonstrate its potential for scaling to other high-value crops and regions in Nepal, contributing to sustainable agricultural development and economic growth in highland regions.

Background

Geographical Context

Sindhuli, situated in Nepal's subtropical highlands, is well-known for its favourable climatic and topographical conditions for cultivating sweet oranges. The region's altitude, ranging from 168 to 2797 meters above sea level, provides the ideal environment for producing high-quality Junar, a local variety. The district contributes significantly to the national output of citrus fruits, with Sindhuli alone producing 8,881 metric tons of sweet oranges in 2022/23.

Despite its potential, the region faces pressing environmental challenges, including soil erosion, unpredictable rainfall, and increasing temperatures. These factors, compounded by inefficient farming practices, jeopardize the long-term sustainability of Junar farming in Sindhuli.

Figure 44:
Sweet oranges grown in Sindhuli.

Socio-Economic Context

Junar cultivation is a critical livelihood for smallholder farmers in Sindhuli, contributing substantially to household incomes and Nepal's agricultural GDP. However, systemic issues such as counterfeiting, where low-quality oranges from other regions are sold as Sindhuli Junar, have led to a decline in consumer trust and farmer profitability. Additionally, poor post-harvest management, including inadequate storage and transportation facilities, exacerbates economic losses for farmers.

Climate Challenges

The highland agricultural system in Sindhuli is vulnerable to climate-induced risks, including prolonged droughts, extreme weather, and declining soil fertility. These challenges underscore the urgency of adopting climate-smart agricultural practices and innovative market solutions to ensure the resilience and productivity of Junar farming.

Rationale

This project aligns with the three pillars of Climate-Smart Agriculture (CSA):

(1) **Increasing Agricultural Productivity Sustainably:** The integration of blockchain-based traceability systems, coupled with training in precision farming techniques, has improved yield efficiency and minimized post-harvest losses. Farmers are now equipped to meet market demands while maintaining the quality of their produce.

(2) **Enhancing Resilience to Climate Change:** The adoption of climate-resilient farming practices, such as organic composting, improved irrigation methods, and the cultivation of drought-resistant varieties, has strengthened the adaptive capacity of farming systems in Sindhuli.

(3) **Reducing Greenhouse Gas Emissions:** By streamlining logistics and reducing food transport miles, the project has significantly lowered the carbon footprint associated with Junar production. The use of digital tools like the KARESA software has also promoted data-driven decision-making, further enhancing sustainability.

Proposed Solution

Climate-Smart Practices and Technologies Implemented

(1) **Blockchain and QR Codes:** The KARESA software introduced blockchain-based traceability, allowing consumers to scan QR codes on Junar packages to verify their origin, harvest date, and journey through the supply chain. This system ensured product authenticity, reduced counterfeit practices, and built consumer trust.

(2) **Food Transport Miles and Carbon Footprint Tracking**: The project integrated food transport miles and carbon footprint tracking into the supply chain. By analyzing transportation routes and production practices, stakeholders identified areas for reducing emissions and optimizing logistics.

(3) **Organic Composting:** Farmers adopted organic composting techniques to improve soil health, reduce dependency on chemical fertilizers, and enhance the sustainability of farming practices.

(4) **Farmer Training:** Training workshops were conducted to educate farmers on blockchain technology, sustainable practices, and branding strategies. These sessions aimed to bridge knowledge gaps and improve the technical capacity of farmers.

Figure 45:
Training sessions conducted to educate farmers about blockchain technology, sustainable practices, and branding strategies.

Role of Stakeholders

(1) **Farmers:** Pilot farmers from Chisapani and Tinkanya cooperatives actively participated by recording production data, adopting QR codes, and engaging with new market mechanisms.
(2) **Private Sector:** Green Growth facilitated the marketing and distribution of Junar, connecting farmers directly with urban consumers.
(3) **Cooperatives:** Local cooperatives provided logistical support, ensuring efficient implementation and mobilization of farmers.
(4) **Government:** The PMAMP Junar Super Zone offered technical and financial assistance, aligning the project with national agricultural goals.

Lessons Learned

(1) **Productivity Gains:** Participating farmers reported a 20% increase in income due to improved market access and reduced post-harvest losses. The use of blockchain technology and KARESA enabled farmers to command higher prices for authentic Sindhuli Junar.
(2) **Consumer Trust:** The project recorded over 3,000 QR code scans, indicating strong consumer interest in traceability and authenticity. This transparency enhanced consumer confidence and contributed to the branding success of Sindhuli Junar.
(3) **Environmental Impact:** The integration of food transport miles and carbon footprint tracking minimized emissions associated with Junar production and distribution. Organic composting further contributed to soil health and reduced environmental degradation.

Challenges

(1) **Infrastructure:** Limited internet access in remote areas posed challenges for blockchain implementation.
(2) **Technical Barriers:** Some farmers faced difficulties in using KARESA due to low literacy levels and unfamiliarity with digital tools.
(3) **Scale Limitations:** Expanding the project requires significant investment in infrastructure and farmer training.

Recommendations

(1) Scaling CSA Adoption
- Expand traceability systems to other high-value crops, such as apples and coffee, to enhance transparency and market competitiveness across Nepal's agricultural supply chains.
- Foster regional cooperatives to enable collective action and resource sharing among farmers.

(2) Policy and Private Sector Engagement
- Advocate for government subsidies to support the adoption of blockchain technology and other digital tools.

- Develop public-private partnerships to address logistical challenges and extend market access.

(3) Consumer Awareness
- Launch targeted marketing campaigns to educate consumers on the benefits of traceability and sustainability, thereby fostering greater demand for authentic local produce like Sindhuli Junar.

(4) Integration of Certification and Traceability
- Combine traceability systems with organic and GAP (Good Agricultural Practices) certifications to further enhance product credibility and market value.

Further Reading

(1) Financial Feasibility Analysis of Sweet Orange Production in Sindhuli, Nepal (Dhakal et al., 2023).
(2) AgriClear Blockchain Documentation.
(3) PMAMP Annual Report 2023.

5. Knowledge and Capacity Enhancement on Climate Change Adaptation

This section focuses on the crucial role of knowledge and capacity enhancement in empowering individuals, communities, and institutions to adapt to climate change and implement climate-smart agriculture (CSA) practices effectively.

Knowledge and capacity building are essential for several reasons. First, they increase awareness and comprehension of climate change, its potential impacts, and the benefits of adaptation and mitigation measures. Second, they develop the skills and knowledge to conduct climate change vulnerability assessments, identify vulnerable hotspots, and prioritize adaptation measures. They also build the capacity of farmers, communities, and institutions to implement CSA practices effectively, considering local contexts and needs. Additionally, they enhance knowledge and skills in sustainable land management practices, such as soil and water conservation, agroforestry, and integrated pest management. Finally, they strengthen the ability of communities to withstand and recover from climate change impacts through collective action and knowledge sharing.

Various approaches can be used for knowledge and capacity enhancement, including:

- **Training programs:** Conduct training workshops, seminars, and farmer field schools to disseminate knowledge and build skills in CSA practices, climate change adaptation, and sustainable land management.
- **Education and awareness campaigns:** Raising awareness about climate change, its impacts, and the benefits of adaptation and mitigation measures through various communication channels, such as social media, workshops, and community meetings. [cite: 733, 734]
- **Knowledge sharing and networking:** Facilitating knowledge sharing and networking among farmers, researchers, policymakers, and other stakeholders to promote collaboration and learning.
- **Community-based approaches:** Empowering local communities to participate in planning and implementing adaptation measures, building on their traditional knowledge and practices.
- **Gender-sensitive approaches:** Ensuring that knowledge and capacity enhancement initiatives are gender-sensitive and address the specific needs and priorities of both women and men.

Institutions, such as government agencies, research organizations, and NGOs, play a crucial role in enhancing knowledge and capacity about climate change adaptation and CSA practices. They achieve this by providing training and technical support, sharing knowledge, and integrating climate change into policies and programs.

These institutions conduct training programs, develop educational materials, and offer technical assistance to farmers and communities. They create platforms and networks for knowledge sharing and collaboration among stakeholders. Additionally, they mainstream climate change considerations into agricultural policies, plans, and programs to support adaptation and mitigation efforts.

Investing in knowledge and capacity building can lead to numerous benefits, including improved decision-making, increased resilience, sustainable agriculture, and empowered communities.

Enhanced understanding of climate change and its impacts enables farmers, communities, and institutions to make informed decisions about adaptation and mitigation measures. Also, a strengthened capacity to adapt to climate change enhances the resilience of agricultural systems and communities, reducing their vulnerability to extreme weather events and other climate risks. Increased knowledge and skills in sustainable land management and CSA practices promote the adoption of environmentally friendly farming techniques, contributing to long-term agricultural sustainability. Finally, knowledge and capacity enhancement empower local communities to take ownership of adaptation and mitigation efforts, fostering self-reliance and collective action.

Selected case studies are presented here to explore the role of knowledge and capacity building in climate change adaptation.

5.1 Case Study 15: Enhancing Capacity of Local Government and Communities in Nan Province

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Abstract

The case study describes a holistic view of Climate SMART Agriculture (CSA), deployed as a platform for policy formulation, sustainable agricultural development promotion and farming community engagement in the Thai highlands. Local government organizations and institutions in the highland agriculture areas of Nan Province gained practical experiences and comprehensive knowledge to apply practical CSA solutions. Government stakeholders, agricultural planning and implementation agencies in Nan Province had the opportunity to compare their current practices on policy intervention with the new CSA based approach which addresses the uncertainty around climate impacts to farming practices. The CSA approach allows government agencies responsible for policy formulation and research and field operation to coordinate data sharing, planning and policy implementation. The sustainable agricultural development plan requires comprehensive data sets and cross-sector analyses to produce useful information for farming communities and institutions to plan and make decisions. The level of climate risk analysis is also included in the CSA to mitigate the adverse effects of climate change at the farm level. In summary, the CSA approach serves as a vital system to cascade information sharing from planning coordination to practical field implementation.

CSA provides a systematic framework to engage farming communities as users of CSA technologies and how best to select and manage those technologies. The CSA approach comprises digital devices to determine the quality and quantity of weather variables and water availability for crop cultivation and farm management. The CSA framework generates data for collaborative decision making at farm, community and regional levels. When needed, it can generate data and produce informational feedback on soil-water-climate management. The CSA framework enables farmers to collectively organize, select, manage and operate CSA technologies to ensure sustainable cultivation planning and farm production. We describe the farmer responses and results of six CSA practices implemented across demonstration sites in Bua Yai Sub-district, Nan Province, Thailand.

Background

Bua Yai Sub-district (BYS) is in the southern highlands of Nan Province, northern Thailand. The agricultural lands of BYS are mostly located in the high-altitude terrains. Local crops are cultivated in local forest areas, severely degraded through both legal and illegal logging over the past 40-50 years ago. The mountain valleys of BYS account for relatively smaller portions of arable land where paddy rice and upland crops are grown. The Haeng River is the only natural stream flowing through the low land areas where local communities can access water for crop cultivation, livestock and domestic use.

The variable topographical terrain of BYS exposing communities and ecosystems to different localized climatic conditions. Accessibility to the area has recently improved through construction of asphalt paved national highways and rural roads, allowing commutes to access public services, businesses, marketing of local agricultural produce and handicrafts, and the development of local tourism.

The farming sector, local service business and local micro-enterprises contribute most to household incomes and livelihoods. In comparison to other northern areas, household incomes are low to moderate. Earning of people in the communities is highly dependent on the sale of farm products, local non-farm employment and employment at local tourist destinations located near to the BYS. Basic livelihood needs and the capacity to earn income were comprised during the COVID-19 pandemic and the associated economic downturn in Thailand.

Farmers and farming enterprises are dependent on either contract farming practices, primarily maize cultivation, or government subsidized community enterprises and private business. A majority of farmers are indebted to loans from both formal and informal sources. There is a widespread perception that they are in a poverty crisis and under-privileged status, and as a corollary, BYS communities continue to request technical and financial assistance from government agencies.

BYS is in a high-risk climate change region, evidenced through rising temperatures, longer and more frequent droughts and intense but less frequent rainfall. For many decades, highland areas have been exposed to soil erosion, degraded soil quality and declining water availability for crop cultivation. Farmers are forced to depend on alternative sources of water for crop cultivation and livestock, primarily provided by the government in the form of an on-farm water allocation system, village ponds for crops, small pumping stations and community water supply units. The Haeng River is usually dry and contaminated with chemicals from farm run-off.

In the steeply sloped areas, contracted maize cultivation has exacerbated topsoil loss and erosion, and the reliance of chemical fertilizers and pesticides has further degraded soil nutrients and soil permeability comprising future rehabilitation.

Most of the agriculture is rainfed. The uncertainty of rainfall and poor soil conditions challenges water conservation through both natural and technical processes. The topographical variability of BYS has led to an unequal distribution of government support of water for crop cultivation, requiring farmers to rely on practical know-how to efficiently use water for agriculture.

Rationale

The capacity development of both local government and local communities is an important component of the sustainable development in highland agriculture. The CSA framework engages local communities and institutions to organize and coordinate planning, management and implementation of appropriate technologies. Provincial, local and community level actors in Thailand are jointly responsible for planning, resource mobilization, coordination, implementation and monitoring of CSA, requiring all to have sufficient practical knowledge and skills to utilize CSA technologies and generated data.

Government agencies at provincial and local levels are typically responsible for assessing climate risk and vulnerability of agriculture ecosystems (see Prabhakar, this volume), and the data output from digital devices to provide recommendations and technical assistance for farmers and farming communities. Farmers can obtain advice from government agencies on alternative crops, production and marketing, scheduling, farm management, soil-water-climate solutions and farming enterprises management. Government staff provide extension support to build the CSA skills of farmers and to problem solve and evaluate alternative CSA options to manage climate uncertainty.

The local government in BYS has been working closely with farmers and farming communities to coordinate the supply of resources for farm management and business enterprises which in turn has raised confidence to adopt CSA practices. The local government also translates provincial agricultural policies to implementable reality at the farm level. Climate resilient agricultural practices will be incorporated into community planning and field actions through local government's facilitation role. Area-based local data are collected and analyzed to verify the coherence of macro and local level data to support decision making of farming communities and enterprise.

Local farmer organizations and enterprises have been formed to ensure productivity and marketability of agricultural producers. Collective enterprises have promoted high quality products that respond to current market demand and continue viable field operations and farm business enterprises with CSA based safeguards to minimize climate risk and for individual farmers to maintain the profitability of farm production.

CSA provides the framework for consistent data sharing and a collaborative decision-making platform that benefits farmer organizations by protecting the natural resources they are dependent on and their livelihoods. Technical support from the local government and field experts helps the transfer of CSA practices and their deployment to BSY farming communities.

Proposed Solution

Climate-smart practice or technology implemented

Climate-smart practices were implemented at six BYS demonstration sites. A solar irrigation system demonstrated the application of renewable energy technology for water management, with a corresponding reduction in green-house emissions. This technology enables farmers to efficiently manage irrigation water as the system provides monitoring data on the watering requirements of cultivated crops. The farm leader of the demonstration site has practical knowledge to operate the solar irrigation system and water distribution system.

Farmers in BYS are now familiar with the application of Biochar materials to maintain soil fertility and soil physical properties. The Biochar raw materials are locally produced from recycled organic waste materials. Biochar can absorb plant nutrients and improve water retention and soil texture promoting crop growth and reduces the carbon emissions of chemical fertilizers.

Farmers participated in the demonstration of the Keyline method for land preparation and cultivation practice in sloping land. The Keyline approach educates farmers to consider water flow direction over sloping land, improving water retention behind ploughed berms, reducing soil erosion, preserving topsoil and conserving soil water for crop uptake. Gravity distributed water can be allocated based on crop needs improving water use efficiency especially in the dry season and droughts. Keyline land preparation requires farmers to adopt new practical skills and machinery operation for land preparation.

In connection to the practical knowledge the farmers had learned on utilization of organic materials for production of Biochar, they started to realize the importance of recycled waste materials and the concept of circularity in crop production. Alternate circular economy practical options were demonstrated by production of biofertilizers from organic waste and compositing from post-harvest crop residues. The latter also promotes carbon free land preparation by avoiding the traditional burning of crop residues and reducing air pollution.

The existing organic farming enterprises which commercialize organic pumpkin production, and a spa perfume made from lemongrass were real business demonstrations for farmers in BYS. The farmers have broadened their perspectives in developing value-added products, primarily certified by national organic farming agencies. The demonstration provides holistic knowledge of management, operation and marketing of organic crops and the application of value-chains in agribusiness management. This demonstration acted as a capacity building platform encouraging farmers to utilize CSA practices and the CSA system to manage farming inputs, promote climate friendly production, optimization of resource utilization, commercialization of products and traceability. The experience and knowledge gained by farmers facilitated direct experience of the CSA practices.

The digital technologies demonstration introduced the application of comprehensive CSA technological solutions in the form of a user ecosystem. The set of technologies comprised digital devices, connectivity for data sharing, data storage, data analytics and data presentation. The combination of different technological components produces information useful for decision making at agency and farm level. The digital components in the CSA solutions generate data based on current conditions in the highlands, which allows users to assess risk caused by climate uncertainty. The data from the technology ecosystem can be cascaded at different administrative and area levels depending on data usage needs and applications. It benefits government agencies, technical support departments, local administration and farming communities.

The CSA technology ecosystem approach emphasizes collective farming organizations assume responsibility for management and operation. In doing so, farmers continue to learn from the use of CSA technology for enhancing climate change adaptation in farming management.

Farmers: adoption rate, challenges and benefits perceived

Several capacity-building events were conducted where farmers in BYS were encouraged to form themselves as farming enterprises (Figure 46). The enterprise then decides on the crops they want to grow and marketing strategies. The enterprise will also use the CSA ecosystem data to plan cropping schedules, farm production and management, harvesting and marketing. The data generated from the CSA ecosystem will help the enterprise to select the appropriate solutions for crop production under the agricultural climatic conditions in BYS.

Figure 46:
Capacity-building events for farmers.

Private sector: tile in financing, technology provision, capacity building and market access

The agribusiness private sector plays a vital role in promoting sustainable agriculture in BSY and the Thai highlands. Private companies can provide support on technological innovations for farm production and CSA-based farm management. Companies can invest in technology and integrate the investment into the business model when they partner with community enterprises. Large private agricultural enterprises or retail companies help farmers to produce high quality products that correspond to consumer demand and improve access to higher value markets. Business partnerships with local farm enterprises provide technical support for crop cultivation, post-harvest management, the sale of produce, market information and customer feedback. The mutual relationship with the private sector enhances learning and helps to build the capacity of local enterprises. Likewise, the partnership with the private sector enables local enterprises to access lower interest financial resources for agribusiness, reducing debt servicing.

Government: Policies, subsidies, or incentives support CSA

The application of the CSA framework across the demonstration sites encouraged government line agencies at national, sub-national and local level to share data planning and decision making on CSA related policies. The system itself facilitates the continuous coordination of technical divisions for the benefit of local stakeholders and farmers. The regular data sharing and coordination provided a platform for the government to assess risk, and design appropriate risk mitigation measures based on current climate risk factors. The data collected by the CSA ecosystem at the local level introduced key feedback responses, evaluations and recommendations for policy formulation at the project and program level. The feedback provides space for the government agencies to verify policies and adjust planning for more sustainable agriculture in the highlands (Figure 47).

Figure 47:
Engagement with government officials.

Non-governmental organizations: Technical support and community engagement

Local stakeholder relations and community engagement proved to be crucial in enhancing sustainable CSA practices. Collaboration increases opportunities for scaling up and replication of CSA practices in other communities in the Thai highlands. With proper policy support and funds, the CSA ecosystem empowers communities to concentrate their resources and efforts into the CSA trials. Both local and international NGOs have human resources and external financial support to support the capacity of local communities on CSA practices. NGOs can also source financial support to replicate the CSA applications in other areas.

Lessons Learned

Productivity gained: improved yield or income for farmers

CSA solutions and ecosystem-friendly farming practices enabled by digital technology increase effectiveness and efficiency of on-farm resource management. The CSA practices demonstrated in BYS revealed improved soil and water conservation, soil fertility and household incomes. Crop selection based on soil suitability and micro climatic conditions increased crop yields. Climate vulnerability assessment supported farmers to avoid growing crops at high risk to unpredictable climate conditions.

Resilience: Reduction in climate vulnerability or resources depletion

CSA practice in the BYS highlands suggests a flexible and responsive approach for farm planning and scheduling for crop cultivation. The data produced from digital technology supported farmer decision making and provided feedback for policy recommendations for sustainable practices. Historical data from the CSA ecosystem assists farmers to better predict the changes in climate conditions and impacts on soil and water resources, enabling farmers to adopt low risk farming practices and select beneficial cropping alternatives.

Environmental benefits: carbon sequestration, biodiversity or reduced emission

Keyline, Biochar and organic farming promoted carbon sequestration and reduced carbon emissions. Exposure to the demonstration sites helped farmers understand farm circularity concepts and to learn CSA practices that improve soil properties and fertility, conserve scarce water for cropping applications and minimize the erosion of topsoil and soil nutrients. Overall, farmers were less dependent on chemical fertilizers and pesticides.

Economic and Social Benefits: Employment, reduced poverty, gender inclusion or market growth

The CSA demonstrations introduced opportunities for BYS farmers to select farming practices, subject to fluctuating climatic conditions, that increase crop yields, reduce costs and increase farm incomes. Establishing local enterprises allowed farmers to properly plan, share risks and realize collective benefits. Demonstrations of CSA practices, and associated capacity building programs, enabled farmers to utilize critical data and access information to use resources more efficiently.

Challenges and Barriers

CSA applications in small farming communities will not attract much interest from private companies to invest or supply CSA technology for farmers because of the narrow scope of economy of scale and low profit margins. Risks of “novel” crop production is also high due to the ability of farmers to successfully fund, utilize and maintain the technology. In attracting private companies to get involved in the CSA, all parties will need to decide on common interests, including shared financial benefits.

Recommendations

(1) MOAC develops specific area-based plan for agriculture development in highlands of Thailand. The ministry can introduce the policy to the provincial administration to promote climate resilience agriculture.

(2) Universities, research institutions and line agencies in environment, climate and water resource sector can enhance collaboration on research and R&D to develop appropriate technologies on CSA and CSA ecosystem which can be applied in the Thai farming contexts. The private sector will be motivated to participate and to provide funding support. Reduction of carbon emissions can be an incentive for the private sector.

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5.2 Case Study 16: Building Climate Resilience through Climate Smart Agriculture in Nepal

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Abstract

This case study explores the adoption of Climate-Smart Agriculture (CSA) practices by smallholder farmers in Nepal's Mid-hills and Terai regions. The study focuses on improving resilience to climate variability, enhancing sustainability, and increasing productivity. The key interventions include drip irrigation, integrated pest management (IPM), biochar production and manure preparation. These practices address challenges such as water scarcity, soil moisture retention, adapting to erratic rainfall, and rising temperatures, contributing to sustainable livelihoods and environmental benefits. The findings highlight the role of capacity-building, multi-stakeholder collaboration, and the tailoring of solutions to local contexts to ensure the successful adoption of CSA practices in fostering climate resilience. This case provides valuable lessons and actionable insights for enhancing CSA adoption in similar agro-ecological zones.

Background

Geographical Context

Nepal's agriculture thrives in diverse agro-ecological zones ranging from the Terai plains to the hilly Mid-hills and high mountainous regions. This study focuses on:

(1) **Buddhabhumi Municipality (Kapilvastu):** A subtropical area in the Terai, vulnerable to droughts and heavily reliant on rain-fed agriculture. This region experiences significant seasonal variability, with decreasing rainfall patterns over the past decades.
(2) **Kageshwari Manohara Municipality (Kathmandu):** Located in the Mid-hills, characterized by moderate rainfall, hilly terrains prone to soil erosion, and growing urban encroachment. This municipality is famous for its agricultural products ranging from seasonal and off-season vegetables to staples like rice, maize, and wheat.

Table 3:
Geographical details of Buddhabhumi and Kageshwari.

Features	Buddhabhumi Municipality	Kageshwari Municipality
Location	Kapilvastu district	Kathmandu District
Altitude (above mean sea level)	94 m - 1264 m	1302 m - 2283 m
Average landholding	0.25 hectare	0.20 hectare
Irrigation	Deep well	Shallow well and River
Crops	Paddy, Maize, Wheat, Mustard, lentils, potato, seasonal vegetables such as cauliflower, carrot, green leafy vegetables	Paddy, Maize, Potato, Vegetables such as cauliflower, carrot, green leafy vegetables.
Market	More subsistence	More commercial

Features	Buddhabhumi Municipality	Kageshwari Municipality
Total Household	1,658 (CBS 2015)	2, 647 (CBS 2015)
Household size	4.67 (CBS 2015)	4.44 (CBS 2015)

Socio-Economic Context

In Nepal, agriculture is the major economic mainstay of more than 70% of the people (CBS, 2013) and contributes about 26.98% of the total gross domestic product (MoF, 2019). Smallholder farmers dominate the sector but face constraints like limited access to modern technologies, fragmented land holdings, and inadequate market linkages. The private sector plays a limited role in technology dissemination and financing, while NGOs fill gaps in capacity-building and community engagement. Kageshwari Manohara maintains a traditional irrigation system, though insufficient for rice, making intensive horticulture dominant. Its proximity to markets ensures a steady supply of perishable vegetables to urban dwellers. Farmers benefit from easy access to inputs and efficient transport, enabling quick distribution to city markets. However, rapid urbanization has encouraged the fragmentation of agricultural land, and it changed into residential or permanent fallow land. In the case of Buddhabhumi Municipality, Kapilvastu, the limited market access and infrastructure make it difficult for farmers to adopt climate-resilient technologies or diversify their crops resulting in mostly subsistence farming (Figure 48).

Figure 48:
Vegetable farms in the semi-urban area (Kageshwari Manohara) and involvement of women farmers.

Climate Challenges

Several studies provide evidence of climate change in agriculture in Nepal owing to the weather dependent farming system. (Chalise et al., 2015). Erratic precipitation patterns (Wang et al., 2013), prolonged dry spells (Dahal et al., 2016; Karki et al., 2017), and intense rainfall (Pokhrel and Hallet, 2015) are becoming more prominent affecting crop production. Specifically, the large inter-annual and seasonal variation in rainfall is making water availability more challenging, burdening already marginalized and smallholder farmers with limited access to resources and livelihood options. The southern plain of the country such as Kapilvastu is already facing water stress for irrigation due to the declining groundwater table (Thapa & Baral, 2013). The major climate challenges of the two project areas are:

(1) **Kapilvastu:** Faces declining rainfall trends, extended dry spells, and rising maximum temperatures. These factors exacerbate water shortages, reducing the productivity of staple crops like rice and wheat. Additionally, the groundwater table is depleting, limiting irrigation access and forcing farmers to rely on deep wells, which are costly and unsustainable in the long run. Soil degradation is another concern, as frequent dry periods, combined with unsustainable farming practices, reduce soil fertility and productivity. The region is also experiencing an increased frequency of extreme weather events.

(2) **Kathmandu:** Experiences erratic rainfall, contributing to soil degradation and a higher prevalence of pests and diseases, directly affecting vegetable farming systems. Similarly, water availability remains a concern, with seasonal water scarcity and heavy reliance on rain-fed agriculture limiting irrigation access and making farming unpredictable. Furthermore, the expansion of urban areas continues to encroach on arable land, increasing competition for essential resources such as water and space.

Rationale

This case study addresses two key pillars of CSA: increasing agricultural productivity sustainably and enhancing resilience to climate change. By implementing scalable technologies such as drip irrigation, farmers have been able to improve resource efficiency and crop yields, particularly in areas facing water scarcity. In Buddhabhumi, drip irrigation adoption reached 100%, demonstrating its effectiveness and scalability in a region experiencing significant declines in rainfall. Similarly, the introduction of biochar and composting technologies has improved soil fertility and contributed to long-term productivity (Pokhrel & Hallet, 2015).

Tailored interventions such as integrated pest management and capacity-building workshops have enabled farmers to adapt to erratic rainfall patterns and rising temperatures. These initiatives equip farmers to address vulnerabilities while fostering a sense of ownership and sustainability. In Kageshwari, 72% of farmers adopted drip irrigation, and training sessions enhanced their skills in CSA practices, showing the impact of inclusive capacity-building approaches.

By integrating local knowledge with scientific solutions, this project has bridged the gap between evidence-based practices and community-driven needs. It underscores the importance of collaboration among stakeholders, including government bodies, NGOs, and the private sector, to create an enabling environment for climate-smart technologies. These interventions demonstrate the potential of CSA to transform agricultural systems and contribute to climate resilience, economic growth, and environmental sustainability (Chalise et al., 2015; Dulal et al., 2010).

Proposed Solution

Status of climate change and people's perception

In Kapilvastu, the annual total wet-day precipitation (PRCPTOT) showed a decreasing trend of 10.86 mm/year. The consecutive dry days (CDD) showed a statistically significant increasing trend at the rate of 1.13 days per year and the monthly maximum value of daily maximum temperature (TXx) of Kapilvastu shows positive trends with magnitude 0.07 0C/year.

Around 50% of the farmers said precipitation is decreasing and are already witnessing longer dry periods. The respondents have faced seasonal droughts, while they are also experiencing extreme rainfall events as stated by 75 % of the farmers.

In Kathmandu, PRCPTOT is increasing at the rate of 3.58 mm per year. CDD was found to have an increasing trend at the rate of 0.52 days per year. The monthly maximum temperature is increasing at the rate of 0.05 0C/year.

The intense rainfall events are becoming more prominent in Kathmandu inducing floods and inundation (Pokhrel and Hallet, 2015). Around 67% of farmers reported an increase in precipitation in Kathmandu. Farmers are experiencing intense rainfall more frequently causing waterlogging problems in the wet season thereby causing a decline in crop productivity. About 78% of the farmers have responded to extreme rainfall.

Co-production of local climate knowledge

Farmers shared that in the year of normal monsoon, rice plantation begins from the third week of May in Kageshwari while in Buddhabhumi plantation starts from the third week of June till the end of July. Upon delayed monsoon, farmers start rice plantation from mid-June until mid-July, in Kageshwari while in Buddhabhumi, after mid-July until the third week of August. The farmers are already experiencing delayed monsoons followed by longer dry spells in both sites. So, over the years, farmers have shifted to commercial vegetable farming instead of paddy, potato, mustard and wheat due to huge returns in the short in Kageshwari. Key informant (KII 04) from Buddhabhumi narrated:

Sowing paddy depends upon the rainfall and since the monsoon is delayed, we are not planting at the same time as we used to.

One of the key informants (KII 01) from Kageshwari narrated:

“Now the farmers have switched to cash crops such as commercial vegetable farming over potato, wheat, mustard in winter and paddy in summer, as there are plenty of hotels and restaurants in the nearby city. This year most farmers have planted rice due to good rainfall, though 90% of the farmers opted for vegetable farming instead of paddy last year. “

Technology and Practices

Since vegetable farming is the major source of livelihood in both municipalities, drip irrigation has been introduced as the core technology which is a low-cost, scalable and climate-adaptive technology prioritized based on the interaction with the farmers considering the dwindling state of water resources. The adoption rate of drip irrigation was found to be 100% as reported by the household survey in Buddhabhumi, while 72% of the farmers use drip irrigation in Kageshwari.

Integrated pest management (IPM) including making bio-pesticides using local resources, improved composting, and the application of biochar introduced as subsidiary technologies.

Farmers played a critical role in adopting these practices. In Buddhabhumi, organized water user groups facilitated widespread adoption. Private sector involvement was crucial, providing technologies, market access, and financial support. Agricultural cooperatives enhanced access to drip irrigation systems and subsidized seeds, leading to increased productivity. Government initiatives, including subsidies and training programs, catalyzed the adoption of CSA practices, while NGOs contributed through community engagement and technical support, ensuring sustainability and inclusiveness.

Capacity Development

In Buddhabhumi, all the farmers strongly agreed that their knowledge and capacity have enhanced after attending training on climate-smart agriculture farming techniques. In Kageshwari 9 farmers agreed and 11 farmers strongly agreed on capacity development through the hands-on training session. Farmers stated that their skill and knowledge of technology and practice of climate-smart agricultural practices have enhanced (Figure 49).

Figure 49:
Women farmers participating in hands-on training session on Climate Smart Agriculture Practices (a) Drip Irrigation application, (b) Information charts and (c) Preparation of compost manure.

Lessons Learned

The project demonstrated significant productivity gains through the adoption of climate-smart technologies. Drip irrigation and biochar application increased crop yields and incomes, especially for vegetable farmers in Kageshwari. Farmers reduced vulnerabilities to erratic rainfall and prolonged dry spells by adapting planting calendars and diversifying crops. Environmental benefits include improved soil fertility and carbon sequestration through biochar and composting. Drip irrigation minimized water waste, promoting sustainable water use. In Buddhabhumi, 100% of surveyed farmers adopted drip irrigation, leading to an increase in crop yields and reduced dependency on unpredictable rainfall. In Kageshwari, 72% of farmers adopted drip irrigation, increasing vegetable production and income due to access to urban markets. A single woman farmer shared that shifting to year-round vegetable farming with drip irrigation allowed her to send her children to school and invest in better farming tools.

Economic and social benefits were also notable. The project created employment opportunities, reduced poverty, and enhanced gender inclusion through targeted training programs. Strengthened market linkages further bolstered economic resilience in both regions. However, challenges persisted, including financial constraints, limited private-sector engagement, and inconsistent policy support. Socio-cultural resistance also hindered the widespread adoption of innovative practices. The formation of a water users' group in Buddhabhumi and the active involvement of agriculture cooperatives in Kageshwari Manohara have helped strengthen community collaboration, improve water resource management, enhance farmers' access to irrigation and easy linkage to access government subsidies for agriculture. One of the smallholder farmers mentioned that they got to know about Nepal's government subsidy programs (especially for limestone distribution) and agriculture extension services.

Scaling these solutions requires context-specific, affordable interventions that deliver co-benefits for climate mitigation, conservation, and economic growth. Stronger public-private collaborations and well-structured policies are essential to bridge financial gaps and sustain growth. Community-driven, data-supported approaches were crucial in building trust and ensuring effective, inclusive action. The integration of scientific evidence, local knowledge and technology transfer ensures sustainable and inclusive solutions to climate-induced agricultural challenges, and this has been well demonstrated through the projects implemented in both locations.

Recommendations

To enhance CSA adoption in similar contexts, tailored training programs and financial incentives are essential. These initiatives should focus on improving access to affordable technologies and addressing site-specific climatic and economic challenges. Farmers require ongoing capacity-building programs to enhance their knowledge and adoption of CSA practices.

The private sector's role in providing financial investments, technology, and market development should be expanded through public-private partnerships. Governments must implement consistent policies, subsidies, and incentives to support CSA practices and strengthen climate resilience. NGOs can play a pivotal role by engaging communities and facilitating participatory, localized interventions.

Integrating traditional knowledge with scientific methods ensures sustainable and inclusive outcomes. Policymakers, researchers, and practitioners should collaborate to develop innovative CSA strategies tailored to local needs. By combining inclusive, evidence-based approaches with strong institutional support, CSA practices can transform agricultural systems, mitigate climate impacts, and improve livelihoods sustainably.

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5.3 Case Study 17: Enhancing Climate Change Adaptation Capacity of Smallholder Upland Farmers in Albay Province, Philippines through Rainwater Harvesting

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Abstract

The upland farming communities in Albay Province, Philippines, face significant challenges from climate change, including erratic rainfall and limited irrigation. Eleven rainwater harvesting facilities (RWHFs) were established to address these issues in three farming communities, benefiting over 120 farmers. These facilities increased water availability, enabling two rice cropping seasons annually, the development of idle lands, and diversification into agroforestry systems. The project involved a multisectoral collaboration among universities, local government units, and farming communities, emphasizing capacity-building and participatory approaches. Key lessons include the value of collective farmer action, tailored solutions for local conditions, and the integration of sustainable land management practices. The project experiences and lessons could be used as a reference by other development programs to replicate this initiative in other upland farming communities in the country.

Background

Smallholder farmers dominate the agriculture sector worldwide. Lowder et al. (2014) reported that 85% of the 525 million farms worldwide are less than two hectares. Rapsomanikis (2015) described them as poor, food insecure, and have limited access to market and basic services. They are the poorest among the rural population because of low farm productivity, limited access to rural advisory services, alternative employment opportunities, and basic social services (Fortenbacher & Alave, 2014). Furthermore, most upland farmers cultivate in marginal lands, with generally steep slopes prone to soil erosion and are rainfed or dependent on rainfall as a source of irrigation (Landicho et al., 2016). Hence, they are also vulnerable to climate change impacts and other weather and natural disturbances.

The 2018 research entitled "Climate change impacts and adaptation strategies of smallholder farmers in selected upland farming communities in Southeast Asia "revealed that upland farming communities have been experiencing climate change but have low levels of adaptive capacity because of limited knowledge and awareness about climate change, limited accumulation of community assets, and weak governance of natural resources (Landicho, Le Van and Ximenes, 2022). In Albay Province, Philippines, for instance, farmers have noted the erratic rainfall pattern, which leads to the lack of water supply for the crops, reduced crop yield and farm productivity, increased expenses in farm inputs, and reduced farm income, As smallholder farmers whose mean monthly income is Php12500 (USD227), they have minimal capacity to invest in agricultural technologies for climate change adaptation. Since their farms are generally rainfed, erratic rainfall often leads to a lack of irrigation water for their crops, especially during the dry season. On the contrary, these communities are along the typhoon-belt areas; hence, during the rainy season, these are sites of heavy downpours, offering rainwater harvesting opportunities.

Rationale

Rainwater harvesting through small water impounding projects (SWIPs) addresses the unbalanced rainfall distribution by collecting and storing direct rainfall and surface runoff for future use (Contreras, et al. 2013). According to Concepcion et al. (2006), SWIPs enhance the multifunctionality of upland agriculture, which could also lead to gaining economic benefits.

Rainwater harvesting was also seen as a technology that would optimize agricultural productivity and develop the resilience of smallholder farmers. Houben et al. (2022) argue that among the ecological indicators is access to irrigation systems, which makes the crops less dependent on rainfall during dry periods. Water availability also determines crop diversity, another resilience indicator, such that a more diverse cropping system leads to A more resilient farming system due to better soil health and slower pest outbreaks.

Given the potential of rainwater harvesting ponds such as SWIPs, the project collaborators proposed a one-year capacity development project to enhance upland farmers' climate change adaptation strategies in Albay Province, Bicol Region, by establishing rainwater harvesting ponds. Specifically, it aimed to: a) develop farmers' knowledge and skills in soil and water conservation, rainwater harvesting, and agroforestry; b) establish at least five (5) RWHFs in each landscape (cluster) in three upland farming communities in Albay Province, Bicol Region; c) develop a monitoring tool that will assess the RWH performance; d) document the lessons and experiences in project implementation; and, e) develop a Manual for the Establishment of Rainwater Harvesting Facility in Upland Farming Communities in the Philippines.

The project was implemented in three upland farming communities: Barangay Malama in Ligao City, Barangay Palanas in Guinobatan, and Barangay Balinad in Polangui, all in the Province of Albay, Philippines.

Proposed Solution

Rainwater harvesting was introduced to the three project sites to address their problem of water scarcity during the dry season and to take advantage of heavy downpours during the rainy season. Through the collective action of the smallholder farmers, 11 rainwater harvesting ponds were established (Figure 50). Two of which measure 30m x 10m x 2 m, which can collect 600m^3 rainwater and can benefit around 20 farmers; four 10m x 8m x 2m, can collect 160m^3 and can benefit 10 farmers each; and five 5m x 10m x 2m ponds that can collect 100m^3 for 10 farmers each (Landicho, et al., 2022) (Figure 51). The farmers were likewise trained in the integration of other supportive technologies, such as agroforestry and soil and water conservation measures, to help conserve and manage soil and water resources while at the same time capitalizing on the rainwater harvesting ponds for crop diversification. Agroforestry systems and soil and water conservation measures were established as demonstration areas.

A Project Facilitating Team (PFT) was formed to ensure smooth project implementation and the sustainability of project initiatives. This team is comprised of key leaders from the three farming communities, who are considered the direct stakeholders and adopters of the technology intervention; the Office of the Municipal Agriculturist of the local government units, which have jurisdiction over the three upland communities, and are providing the technical and policy support programs in agricultural development; and the local state university, which is the source of technical expertise. The PFT works closely with the University of the Philippines Los Banos (UPLB) team, who take the lead and catalyze project implementation. The youth leaders were called Local Monitors, who regularly monitor project activities. They serve as a link between the local partners and the UPLB-based project team, especially during the height of the COVID-19 pandemic.

Figure 50:
Co-establishment of rainwater harvesting facilities harnessing the collective action (bayanihan) of farmers in the three upland farming communities.

Figure 51:
The type and size of rainwater harvesting ponds vary across the three project sites, depending on their local conditions.

Lessons Learned

(1) Rainwater harvesting ponds have improved crop production in the three project sites and motivated them to expand their cultivation areas. Most farmers are now producing rice in two cropping seasons from one cropping season because of the efficient rainwater collection and storage of the ponds. Some farmlands that used to be idle have been developed because of water availability. Other rice farmers have expanded their area and diversified crop production.

(2) Addressing the needs of farmers and local communities ensures their genuine participation. The genuine participation of the local communities is harnessed when the development programs are centred on their felt needs. This also develops their sense of ownership in all of the project undertakings.

(3) Emphasizing capacity development ensures active stakeholders' engagement. Cross-farm visits and on-site training helped farmers appreciate the technology's workability in their sites. Harnessing the potential of the farming communities and the local government units also ensured genuine participation.

(4) Understanding the local conditions matters. There is no standard size, type, or process for establishing rainwater harvesting facilities in upland farming communities. It all depends on the expressed needs and local conditions, farm size, type of crops, geographical conditions of the community, the number of farmers who would use the resource, and the farmers' commitment to establishing and maintaining the facility.

(5) Multisectoral collaboration confirms well-organized, efficient, and effective project implementation. This form of partnership enhances the mindset of direct and indirect stakeholders about their roles in enhancing agricultural productivity, promotes resource sharing, ensures focused project development without duplication of efforts, facilitates smooth project implementation, and paves the way for the sustainability of the project initiatives.

Recommendations

Based on the experiences and lessons learned, the following recommendations are hereby proposed for upland farming communities with similar vulnerabilities and challenges in agricultural production:

(1) *Building the capacity of smallholder farmers for climate change adaptation requires multisectoral collaboration.* This group shall comprise the local government units that can institute and execute local policies, the academe or university as sources of technical expertise and advisory services, and the communities that adopt technological interventions. This core group shall take the lead and catalyze the implementation of various activities revolving around need-driven technology interventions.

(2) *The technology intervention should promote nature-based solutions to address sustainable development*. For smallholder upland farmers who cultivate marginal areas (e.g., rainfed, sloping, low soil fertility), agroforestry and soil and water conservation measures are important components of technology interventions.

(3) To ensure the genuine and active engagement of the different stakeholders, particularly the local communities, capacity development and participatory approaches should be embedded in all aspects of project implementation. Conde and Lonsdale (2006) argue that their adaptive capacity is being developed in engaging the stakeholders because people are given time to strengthen their networks, knowledge, resources, and willingness to find solutions.

(4) Promoting policy-science linkage facilitates the institution of local policies, which could lead to the sustainability and scaling-up of project initiatives. Consultations and involvement of the local government units in project implementation are among the strategies that make policy-makers aware of issues and problems, thereby encouraging them to take policy actions.

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5.4 Case Study 18: Restoring Ecosystems and Livelihoods: Agroecological Innovations in the Manupali Watershed, Mindanao, Philippines

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Abstract

The Manupali Watershed in the Philippines, part of the Mt. Kitanglad Range Natural Park (MKRNP), is a vital highland ecosystem threatened by unsustainable farming practices and climate change. This ca se study showcases agroecological landscape restoration as a solution to restore degraded ecosystems, enhance biodiversity, and improve livelihoods. Four demonstration farms were developed using tree-based agroforestry systems and participatory planning with farmers, local government units, and NGOs. Restoration plans incorporated native tree planting, soil conservation measures, and crop diversification, balancing conservation goals with the farmers' socio-economic needs. Key outcomes include improved ecosystem services, reduced erosion, and strengthened community engagement. Lessons from the project highlight the importance of participatory governance, indigenous knowledge, and tailored restoration strategies, providing a replicable model for sustainable upland farming in other regions.

Background

The study was conducted in the Manupali Watershed. This watershed is part of the Mt Kitanglad Range Natural Park (MKRNP) in Bukidnon province of Mindanao, Philippines, under the ADB TA-6539 REG: Investing in Climate Change Adaptation through Agroecological Landscape Restoration - 1 Climate Change Risk and Adaptation/Restoration Option Assessment in Cambodia, Myanmar, and Philippines.

The watershed is part of the few remaining primary forests in the country, which is a biodiversity cradle, e.g. the famed but endangered Philippine Eagle and the world's second-largest flower, Rafflesia schadenbergiana. The MKRNP is the place of abode for indigenous peoples like the Talaandigs and Higaonon. It houses the province's food basket, where farmers produce maize, coffee, potato, cauliflower, cabbage, carrots, Chinese pechay, and many other vegetables. Downstream major crops include maize, sugarcane, and irrigated rice. The project site is part of the Upper Bukidnon River Basin, which is part of the larger Mindanao River Basin. The rivers flow through a network of irrigation systems supporting a hydropower facility (Pulangi IV).

Forest cover is 36.43 % of the area (28.64% closed forest and 7.79% open forest), annual crops are almost half the total land area (46.03%), and perennial crops constitute 5.25%. Population migration and encroachment into the natural forests have converted significant portions of the watershed into intensive upland agricultural farms and built-up areas. In addition, the lack of livelihood opportunities, the inadequacy of plans and programs to protect the forest, and poor enforcement of laws and regulations, including poor governance, have continued to threaten the integrity and health of the Manupali watershed (Watershed Management Plan of the Manupali River WMU). Siltation into the Pulangi IV HEP Reservoir was estimated to be 1.5 MCM annually. These environmental problems have been exacerbated by climate change, which is predicted to result in wetter and drier dry seasons. Drought has been experienced by many of the stakeholders as a serious problem hounding their farms and the town's domestic and industrial water supplies.

Rationale

Unsustainable upland agriculture characterized by monoculture cultivation of annual crops with tillage and high chemical inputs plagues significant portions of the MKRNP. Continued encroachment, even up the buffer zone of the Natural Park, appears to be the norm rather than the exception. Demand for highland vegetables like lettuce, carrots, cabbage, broccoli, potatoes, and the like continues to soar, further encouraging farmers to clear the remaining forests of the

MKRNP, resulting in more significant forest degradation and increased forest fragmentation. Consequently, biodiversity is significantly reduced, soil erosion and sedimentation rates escalate, soil resources become more impoverished, hydrologic traits have become unstable, and significant declines in forest products like fuelwood and non-timber forest products as well in other ecosystem services like biodiversity, C sequestration and microclimate amelioration. Climate change intensifies these negative impacts, which has eventually affected farm productivity and farmers' income. Therefore, the vicious cycle of forest degradation and poverty is further heightened. This dismal state necessitates radical transformation of the current destructive practices. Otherwise, it may reach the tipping point of an almost irreversible state.

Agroecological landscape restoration is a comprehensive and holistic approach towards addressing the diverse ecosystems and often conflicting goals in watersheds by several stakeholders. This approach is a potential solution to address the global challenges, including climate change, food security and sustainable development. In the context of the Manupali Watershed, agroecological landscape restoration can rehabilitate impaired ecosystem functions towards more biodiverse, productive and climate-resilient ecosystems.

Proposed Solutions

Following the key principles of agroecology of diversity, efficiency, resilience, recycling, social equity, and co-creation of knowledge, restoration plans for four (4) demonstration farms of selected farmer cooperators were crafted in a participatory scheme. Additionally, the principles of Forest and Landscape Restoration were incorporated in the process of developing these demo farms, which are: focus on landscapes, engage stakeholders and support participatory governance, restore multiple functions for multiple benefits, maintain and enhance natural forest ecosystem within landscapes, tailor to the local context using a variety of approaches and manage adaptively for long-term resilience.

Participatory mapping with the individual farmers generated the current conditions of their respective farms (Figure 52). With guidance from the project specialists, including other major stakeholders (local government unit officials, representatives from academe, private sector and other government agencies), the farmers identified the issues, challenges and concerns confronting their farms and the larger landscape (or watershed). Through a series of workshops, including cross-farm visits, the farmers, the project team, and a local environmental NGO crafted restoration plans based on specific goals and identified the farmer cooperator. The restoration plan underwent several iterations to reflect the farmer's aspirations and vision for the future. Using a complex tree-based agroforestry system promotes biodiversity that assures resilient ecosystems that are also market-responsive and stable. This ensures farmers of both adaptation to climate change and the dynamic market forces.

Figure 52:
Participatory mapping.

(1) One farm in the buffer zone of the MKRNP has the restoration objective of protecting the remaining natural forests, improving hydrological systems, promoting biodiversity conservation and enhancing livelihood opportunities. The farm will practice crop diversification and rotation and planting native trees, fruit trees (e.g. coffee), and non-timber forest productions (NTFPs) (Figure 53). Alleys were established by laying the contour lines using an A-frame (Figure 54).
(2) The next farm intends to transform the farm from a vegetable to a tree-based system while ensuring income during the transition. Native tree species are integrated into the design along the perimeter and the creek and as hedgerows in areas cultivated with vegetables.
(3) Another farm will integrate native tree species in six different locations across the farm: (i) along the perimeter, (ii) in a portion of the remaining forest area with gentler slope and lower tree densities, (iii) in coffee planting areas to provide shade (iv) along the waterline to provide greater structure, (v) along the contour lines of sloping vegetable areas in combination with Napier grass (Pennisetum purpureum), and (vi) in the lower part of the farm where the farm is considering planting coffee shrubs.
(4) The next farm introduces native tree species as mixed secondary and natural forests and within vegetable areas as hedgerows along contour lines using the SALT technique. The design includes a nursery to produce fruit or forest timber trees, coffee, and cacao, using quality mother plants. Likewise, Calliandra and madre de agua trees are options for nitrogen fixing and fodder. Between the hedgerows, a diverse range of crops are planned, including root crops such as camote, gabi, or cassava; high-value crops such as broccoli, cauliflower, cabbage, and lettuce; herbs or spices such as lemongrass, onion, garlic, ginger, and turmeric; and medium-term crops such as banana, coffee, cacao, avocado, and passion fruit. Native tree species, which are deep-rooted, like madre de agua, native guava, or tibig, will be introduced along the existing drainage corridors to avoid severe gully erosion.
(5) One farmer-cooperator backed out due to the misconception that planting native trees and their subsequent harvest would subject him to legal cases for timber poaching. No clarification or explanation changed the family's mind on this wrong perception.

Lessons Learned

The study generated the following vital learnings:

(1) The imperatives for an integrated and holistic approach that also considers the stakeholders' social, environmental and economic goals promote better engagement and support from farmers.
(2) Balance what people will have in the future (conservation) while also paying attention to what they need today (livelihood, food security, and climate resilience)
(3) The importance of taking into consideration indigenous knowledge and practices. Mt. Kitanglad Range Natural Park has a cultural significance to the Talaandig tribe; caring for the watershed is part of their culture.
(4) The role of farmers' aspirations in their land use. Considering not only what they know but also what they envision for their lands will help to plan sustainable restoration efforts effectively.
(5) The benefit of building a strong and accessible climate-related information and database as a support tool.
(6) The need for appropriate and fair incentives to encourage adoption and investment in FLR with smallholder farmers and rewards for sustainability and scale
(7) The importance of building local capacity and replicating climate-based solutions through demonstration activities. Demonstrating appropriate nature-based solutions for improving climate resilience helps in upscaling.
(8) Strong Institutional support and participatory governance is vital for Forest and Landscape Restoration.
(9) Active Engagement of Stakeholders and Participatory Planning & Monitoring at the Landscape Level.

Figure 53:
Laying out contour lines in demo farms in the MKRNP buffer zone using improvised A-frames.

Figure 54:
Farmer planting native trees in alleys with vegetables.

Recommendations

(1) Institutionalization of the Lantapan Manupali Watershed Management Council (LMWMC) and implementation of its 5-year road map to sustain the initial project efforts of restoration.
(2) Building on incentives and/or reward systems for watershed management, including FLR.
(3) Integration of demonstration farms as learning sites in Lantapan's programs and projects related to: (i) environmental protection, (ii) agricultural development, (iii) agro-ecological tourism, etc.
(4) Localization of GESI-related national policies and programs.
(5) The local environmental NGO (Landcare Foundation of the Philippines), through the Provincial Tribal Council of Bukidnon, will continue facilitating the demonstration sites with the farmer-cooperators with new FLR-related projects.
(6) Tap the private sector through the LMWMC to finance the expansion of the restoration works.

Further Reading

(1) International Centre for Environmental Management (ICEM) and World Agroforestry (ICRAF). 2024. Restoration Plans for Demonstration Areas in Cambodia and the Philippines Technical Assistance Consultant's Report for ADB TA: Investing in Climate Change Adaptation through Agroecological Landscape Restoration: A Nature-Based Solution for Climate Resilience (Draft report, official links to be provided later).
(2) International Centre for Environmental Management (ICEM) and World Agroforestry (ICRAF). 2024. Integrating the Principles of Ecological Agriculture into Upland Farming Systems of the Manupali Watershed in the Philippines. Technical Assistance Consultant's Report for ADB TA: Investing in Climate Change Adaptation through Agroecological Landscape Restoration: A Nature-Based Solution for Climate Resilience (Draft report, official links to be provided later).
(3) International Centre for Environmental Management (ICEM) and World Agroforestry (ICRAF). 2024. Community-based Climate Vulnerability Assessment and Adaptation Planning for Resilient Agroecosystems. Technical Assistance Consultant's Report for ADB TA: Investing in Climate Change Adaptation through Agroecological Landscape Restoration: A Nature-Based Solution for Climate Resilience (Draft report, official links to be provided later).
(4) Stanturf, John; Mansourian, Stephanie; Kleine, Michael; eds. 2017. Implementing Forest Landscape Restoration, A Practitioner's Guide. International Union of Forest Research Organizations, Special Programme for Development of Capacities (IUFRO-SPDC).Vienna, Austria. (pages 8-9)

5.5 Case Study 19: Alternate Wet & Dry Paddy Rice Planting increased yield and reduced emissions in Xundian County, Yunnan Province

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Abstract

The objective of the project was to demonstrate that the change of paddy rice cultivation to alternate wet & dry precision cultivation could both improve yields – the motive for farmers – and reduce methane emissions – the need of humanity and was acceptable to the local community and could reach high uptake.

The project realized its objectives, increased yield by 25-33%, reduced 5 tons/ha CO2e in methane emissions and created a win-win situation. The project further sensitized the community on other environmental issues and successfully promoted the reuse of crop residues, organic fertilizer, intercropping of corn and legumes, green manure, vetiver grass on contours to reduce soil erosion and increase plant biomass; rice-ducks method to reduce insecticides. A nature-based 'Rice tail water treatment' ditch pilot further cleaned 2/3 and ¾ of non-point nitrogen and phosphorus pollution and demonstrated proof of concept. Any agricultural planning should relate to climate change and based on the local conditions create similar win-win situations for people and the planet.

Background

Located in the middle of the Yunnan-Guizhou Plateau, Xundian County (latitude 25.56° north and longitude 103.25° east)has very complex landforms, including mountains, hills, slopes, dams, and valley troughs. Most of the 3,588 km^2 are between 1800-2600 meters above sea level, mountains account for 87.5 %, the highest elevation is 3300 m, lowest is 1440 m.

Xundian has a low-latitude plateau monsoon climate, which is controlled by the horizontal westerly circulation in winter and spring, with drought and little rain. Summer and autumn are mainly controlled by warm and humid air, the oceanic monsoon climate is prominent, wet and rainy.

Terrain height and climate differences are large, and the three-dimensional climate is obvious. The average 2000-2020 annual precipitation was 1018 mm, temperature 15.3 °C, sunshine duration 2,046 hours, with clear tendencies to less rain, and more heat and sunshine. In 2023 precipitation was 696 mm, temperature 16.2°C, sunshine 2193 hours.

Xundian is a sub-district of Kunming Municipality, 90 km from the urban center. Most young people work outside of the county. The officially registered population is 580,000, with 77% rural, spread over 1577 natural villages with an average of 775 people or 220 families, with 400-500 people usually working outside the village. The government invested in specialty cash crops (tobacco, kiwi, vegetables, flowers, beef and mutton), and the county was among the first 15 counties in Yunnan to eradicate absolute poverty in Yunnan in 2018. Risks like temperature and drought increase, soil degradation and erosion prevail due to its location and topography.

Rice was transplanted in May and harvested in September. The water level used to be 5-8 cm high for 4 months, interrupted by about 2 times of drainage. Methane emissions used to be 180 or 240 tons CO_2e./ha in the 2 villages. Awareness of pesticide toxicity and the potential harm of too much fertilizer application was low.

Rationale

Smallholder agriculture in the mountains of Southwest China is characterized by small landholdings, spread over various plots, elderly often semi-literate labour with the younger villagers working in urban centres for higher income, with unstable markets and unsustainable utilization of chemical fertilizer and pesticides. The objective economic difficulties make more and more farmers leave their land unused. '26.47 million hectares of cropland were abandoned from 1991-2018 (including cropland that has been reclaimed). Under the positive influence of the government's food security policy, the abandoned cropland has decreased in recent years, but the total area is still high.

Yunnan province mountain families have ~1/3 ha of arable land for survival. Highland smallholders aren't causing climate change and shouldn't be forced to reduce emissions - we should find mitigation methods where that simultaneously increase production, so there is a double benefit for farmers and nature.

Most resident elderly farmers are semi-literate and lack technical skills. China's ~120M hectares of arable land cause 787 Mt CO2e emissions, and paddy rice methane emissions are 147 Mt (18.7 %). Another 32% are caused by synthetic fertilizers.

Due to the extensiveness of agricultural production, agricultural non-point source pollution is one of the biggest causes of water pollution. In the past 30 years, to meet high and stable crop yields, the use of nitrogen fertilizer in China has increased 4x, but at the same time, the utilization rate of nitrogen by crops is only 30 %.

The latest (1984) soil survey showed that organic carbon content is >30% lower than the global average. Turned around, there is huge carbon sequestration potential.

"Over the next 50 years, effective farmland management practices (organic fertilizer application, straw returning, conservation tillage) could contribute ~30-36% to soil carbon sequestration"[13].

To alleviate the above-stated problems, HPP implemented the 'Farmers' Clubs Xundian Project' over 4 years (2015-2018) in Hekou Town, Xundian County, benefiting 1040 Households on 316ha.

Proposed Solution

We organized the community into voluntary 23 Farmers' Clubs (FC) of an average of 45 elderly farmers per FC.

FC subgroups (core groups') of 10 farmers met monthly for training and project M&E, our project hired 1 local volunteer ('Farming Instructor') per village fulltime for daily field - and home visits under the leadership of resident project manager (in HPP projects managers reside for usually 3 years in the rural areas we aim to impact). Farmers were taught to use Achievement Books where to record yields, sales, income per unit, costs and labour used. Pre-project most elderly farmers did not keep household records and were unable to set up budgets.

We promoted the Rice Precise Quantitative Planting Technology (RPQPT) of Yunnan Academy of Agricultural Sciences (YAAS).

Instead of high-density planting (120 -135 kg seeds per ha), fixed planting techniques of 10 x 20 cm distance (resulting in 75 - 90 kg seeds/ha) and alternate wet-dry water management were instructed by a YAAS expert who could allocate 1 annual training per year.

The locally resident project Farming Instructor daily reinforced YAAS training content, which enabled farmers to grasp and implement the techniques (Figure 55).

[13] Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Dr. Li Hu, https://www.iarrp.cn/ysdt/mtbd/292422.htm

Annually, the community interest grew after seeing yield improve to 7.8 - 8.7 tons/ha, compared with the original 6.0 - 6.7 tons/ha - a 25 – 30 % increase, and planting area increased.

To prove emission reduction, we weekly took air samples and measured methane emissions in cooperation with Yunnan Academy of Scientific & Technical Information (YASTI), following the Clean Development Mechanism (CDM) methodology - "CMS-017-V01 Reducing Methane Emissions by Adjusting water supply Management Practices in Rice Cultivation" (Figure 56)

A static chamber method was adopted for field observation of methane gas in the trial field and control fields. Weekly samples were taken to laboratory testing in Kunming and analyzed by gas chromatography with a hydrogen flame ionization detector (FID).

We piloted a nature-based ‘Rice tail water treatment’, developed by YAAS. A treatment pond was established 10.2 m x 9.3 m 0.8 m. In the pond, water spinach, water cabbage and mint were planted. Chinese arrowheads were planted in a 33 m collection ditch. 99 Water samples were collected over 25 weeks and compared by pollutants: River irrigation water, paddy water, tail water discharged, and processed tailwater.

We promoted conservation farming. Besides the RPQPT, we promoted the reuse of crop residues, organic fertilizer, intercropping of corn and legumes, green manure, and vetiver grass on contours to reduce soil erosion and increase plant bio mass; rice-ducks method to reduce insecticides.

As a start in 2015, two RPQPT pilots covering 124.5 mu were respectively set up in the two targeted villages. The whole RPQPT project began its preparation in March and was monitored & instructed by a number of professionals (YAAS, YASTI, local agricultural extension workers, HPP farming instructors and the HPP project manager. On top of RPQPT rice planting, 95 mu intercropping of corn and legume was cultivated from May, 4 Solar Insecticidal Lamps were setup in July, 121 mu broad bean & 1114 mu vetch was planted in October, 2mu no-tillage potato was planted in December and the whole idea of a crop rotation concept was introduced and adopted by many farmers.

Figure 55:
Training farmers on RPQPT.

Figure 56:
Weekly air sampling in collection boxes for methane content measurements.

Role of Stakeholders

Adoption rates tripled from about 25 % of farmers to 75 %. Challenges were about bi-annual flooding of the Niulan River where farmers still could see, that RPQPT rice performed better than non- RPQPT. Benefits were the 25 – 33 % increase in rice yield and income, and reduction in seed, transplanting and irrigation costs. The private sector was not involved in our project. At that time there were no government subsidies, or incentives supporting CSA, but YAAS had the task to promote RPQPT. Currently, at least two other Non-Governmental Organizations (NGOs) are working on rice cultivation improvements and emission reduction.

Lessons Learned

Farmers' Clubs

(1) Participation grew from 364 HH (2015) to 1040 HH(2018)
(2) FC met monthly and increased knowledge, skills, yields, and unity.
(3) Organized in producer clubs, also semi-literate villagers mastered new technologies.

Rise Precise Quantitative Planting Technology (RPQPT)

(1) RPQPT is a proven technology. Compared with traditional methods, the RPQPT used less fertilizer, pesticide and water, it improved rice production by ~ 30 %. RPQPT with alternate wet-dry irrigation reduced methane emissions and increased farmers' income.
(2) The rice area increased from 124 x 15 = 8.26 ha (2015) to 739 x 15 = 49.26 ha (2018) as farmers saw the real results.
(3) Rice yield increased from 432 x 15 = 6.48t/ha (2014) to 574 x 15=8.61 t/ha (2016), but in 2 years of flooding (2015+2017) decreased to 3.5 & 6.7 tons/ha.
(4) Based on the weekly methane measurements, YASTI calculated CO2 e. reduction of 4.0-5.0 tons/ha. (2 annual reports).
(5) RPQPT was only introduced on 200,000ha in Yunnan, 800,000ha do not yet use it.

Tail water treatment

(1) The result showed a pre-intervention water nitrogen level of 7.50mg/L, a post-level was 2.56mg/L. The phosphorus pre-level was 0.23mg/L, post-level was 0.06mg/L. Treatment Pond can effectively purify paddy tail water and reduce pollution of Niulan River which is a tributary to Dianchi Lake (512km2) and its water part of the lake restoration.
(2) Villagers' awareness of environmental protection improved.

Conservation Farming

(1) 1,114mu;15=74.3ha Hairy Vetch cultivation annually was work intensive, but farmers saved 62.4 tons of fertilizer in the next planting, preventing water loss and soil erosion.
(2) 2 years' inter-planting of maize and broad beans on 618Mu:15=41.2ha didn't' increase corn yield but added bean yield(32x15=480kg/ha); estimated herbicide saving 111kg.
(3) 6,000m vetiver-grass prevented slope-erosion.
(4) Experimental rice-ducks farming: 190 ducklings/ha keep weeds down.

Financial efficiency

Project costs (excluding methane measurements): 1,680,000 CNY (240,000 USD). The extra income generated: 731,703 CNY (104,529 USD). Experiences gained and published. Local capacity increased.

Social efficiency

As a non-profit with a resident project team, we became a bridge between experts and villagers.

Community benefits

Farmers have seen that the number of irrigations and the amount of irrigation water for rice have decreased a lot compared with the past, but the growth and yield of rice are better than in the past. This has made farmers realize the benefits of breaking the traditional concept and learning to use new technology and increased their interest in learning to use new technology. Farmers improved income by reducing seeding and transplanting costs by 30 %, reducing irrigation costs, and increasing yield and sales income by 30%.

The implementation of the project has improved the environmental protection awareness of farmers to some extent. For example, while guiding farmers in the prevention and control of rice pests and diseases during the rice planting process, the project also explains to farmers the knowledge of pesticide use, to deepen farmers' understanding of the harmfulness of pesticides to the body and the environment. Farmers' correct use of pesticides reduces the number of pesticides used, and when using pesticides, they also know to take protective measures. At the same time, they dispose of leftover pesticides and waste properly, reducing the damage to the body and the environment caused by using pesticides. Farmers also have learned to apply fertilizer more targeted based on soil fertility.

Recommendations

After having eradicated absolute poverty in 2020, there were still over 544 million people living in rural areas, with 2.65 times less per capita disposable income than their urban peers. The government aims at ‘5 Rural Revitalizations’ (economic, ecological, cultural, human resources, organizational), all of which are supported in our Farmers’ Clubs model. We need to improve income and quality of life for the average 65-year-old farmers left behind in remote villages, still toiling the land for another 15-20 years.

The global mean temperature in 2023 was 1.45±0.12°C above the 1850-1900 pre-industrial average (WMO). Extreme heatwaves, drought and devastating flooding have affected millions and cost billions. Smallholders are both victims of an increasingly unstable natural environment and potential stewards of tomorrow by protecting the water and soil of the planet.

We should bring known low-cost solutions like those presented above from research institutions to the villages through local government structures, mass organizations, NGOs, farmer cooperatives, or revitalize traditional knowledge and get community structures to work, and ‘bridge the last mile’ by assisting communities in doing localized interventions to stop ‘Global Boiling’ (Guterres) with focus on adaptation and protection of life and livelihood in increasingly extreme weather.

Strategies to enhance CSA adoption in similar contexts must be based on local context and be community-led to have long-term effects. China needs ‘township level’ adaptation and CSA plans in all its mountain areas, due to its complicated geography. Like China organized the 2011-2020 poverty alleviation campaign, China will need a national adaptation and CSA campaign. To prepare for this campaign, pilots should be started from 2025-2030.

Further Reading

(1) 2016-05 Print edition No. 174, NONGCUN SHIYONG JISHU (Practical Village Technologies), page 36-37 Study on carbon emission reduction in water supply management for rice cultivation in Xundian
(2) 2018-02 Print edition No. 195, NONGCUN SHIYONG JISHU (Practical Village Technologies), page 32-36 Experimental study on tail water treatment in Xundian paddy field

6. Workshop Summary, Conclusions, Recommendations and the Way Forward

Asian highlands face a complex interplay of environmental, social, and economic challenges that hinder sustainable agricultural development and food security. These challenges are further exacerbated by the impacts of climate change, which include increased temperatures, changes in rainfall patterns, and more frequent extreme weather events The workshop provided a valuable platform for knowledge exchange, bringing together policymakers, researchers, practitioners, and farmers to discuss challenges, innovations, and strategies for CSA implementation.

A significant part of the discussions focused on two key sessions, discussed below in 6.1 and 6.2.

6.1 Experience Sharing on Pilot Demonstrations by Farmers in Bua Yai Subdistrict, Na Noi District, Nan Province

This session highlighted real-world experiences of farmers implementing CSA in highland areas, emphasizing:

(1) **Adoption Challenges**: Farmers initially faced difficulties due to limited awareness of CSA techniques, high upfront costs, and uncertainty about returns on investment.
(2) **Benefits Observed**: Over time, CSA practices such as soil conservation, agroforestry, and organic fertilizers led to improved soil fertility, higher yields, and better water retention.
(3) **Lessons Learned**: Farmers emphasized the importance of continuous support, access to technical training, and incentives for smallholders to facilitate the transition to CSA.

6.2 Climate-Smart Agriculture Investment Planning for Highlands

Discussions in this session centred on the financial and policy frameworks needed to scale up CSA adoption in highland regions:

(1) **Investment Challenges**: Limited financial resources, fragmented funding mechanisms, and a lack of tailored investment models for highland agriculture were identified as significant barriers.
(2) Strategic Recommendations:
   - **Public-Private Partnerships (PPPs)**: Encouraging collaboration between governments, private investors, and community-led initiatives to ensure sustainable funding for CSA projects.
   - **Incentive Mechanisms**: Developing financial incentives, such as subsidies for climate-smart inputs, carbon credit programs, and access to low-interest loans for CSA adoption.
   - **Capacity Building and Knowledge Sharing**: Strengthening extension services to provide farmers with the technical skills needed to implement CSA effectively.

The insights from these sessions directly inform the recommendations and strategies outlined in *The Way Forward for Scaling Up CSA in Highlands* (see Pages 106-107). Key takeaways include:

(1) There is a need for **CSA integration into local development planning** to ensure long-term sustainability.
(2) Addressing **challenges of CSA adoption** through targeted financial support, training programs, and community-driven initiatives.
(3) Strengthening **governance frameworks** to align CSA efforts with broader agricultural and environmental policies.

By incorporating these learnings into actionable strategies, the workshop has laid the groundwork for more effective CSA adoption and investment in highland regions.

6.3 Summary

The opening session provided an overview of the workshop participants, highlighting their diverse backgrounds, nationalities, and sectoral representation. The participants included government staff, development partners, farmers, academia, and the private sector.

The speakers emphasised the project's objectives, which include reducing vulnerability, enhancing adaptive capacity, improving agricultural competitiveness, promoting sustainable land use, and strengthening the capacity of local governments and communities. The project's expected outcomes included creating an enabling environment for adopting CSA practices and improving the livelihoods of highland communities, were also discussed.

The speakers highlighted the project's focus areas, including geographic regions (highlands of Nan Province), specific crops and agricultural practices (sustainable soil and water management, keyline ploughing, solar irrigation, biochar application, and organic agriculture), and capacity building through training workshops and knowledge-sharing activities.

The speakers stressed the importance of collaboration among various stakeholders, including government agencies, research institutions, and local communities, to achieve the project's objectives and promote sustainable agricultural development in the highlands.

Some key points emerged from the presentation and panel discussion are summarised below:

(1) Deforestation and land degradation are critical environmental issues in highland areas, driven by unsustainable farming practices, insecure land tenure, and limited awareness. These challenges are further exacerbated by climate change impacts, including increased temperatures, changes in rainfall patterns, and extreme weather events, contributing to water scarcity. Socioeconomic challenges, such as poverty, food insecurity, and land tenure issues, further complicate the situation.

(2) Water scarcity and soil degradation are significant challenges for highland agriculture, driven by unsustainable farming practices and the lack of water resources. To address these challenges, climate change vulnerability assessments are essential for understanding potential impacts and identifying appropriate adaptation measures. Various methods can be used for these assessments, including experimental, modelling, indicator-based, and scenario-based analyses. These assessments help identify vulnerable hotspots – areas or communities particularly susceptible to climate change impacts.

(3) Climate-smart agriculture (CSA) practices aim to simultaneously achieve increased productivity, enhanced resilience, and reduced emissions. Sustainable soil and water management practices are essential for maintaining the highlands' productivity and resilience of agricultural systems. Keyline ploughing and solar irrigation are CSA practices that can help conserve water and improve crop yields in drought-prone areas. Biochar application and organic agriculture can improve soil health, enhance biodiversity, and reduce environmental pollution.

(4) Product quality and safety are paramount for consumer trust and market access. Efficient value chains and strong market linkages are essential for connecting farmers to consumers and ensuring that agricultural products reach the market at competitive prices. Digital technologies can play a transformative role in improving the efficiency and transparency of agricultural value chains.

(5) Knowledge and capacity enhancement are essential components of climate change adaptation initiatives. Empowering farmers and communities in highland areas involves equipping them with the knowledge, skills, and resources necessary to adapt to the impacts of climate change. Building the capacity of local governments and institutions is crucial for mainstreaming climate change adaptation into policies, plans, and programs. Training and knowledge-sharing activities are essential for disseminating information, building skills, and promoting climate-smart agricultural practices.

6.4 Conclusions

Collaborative Action for CSA. Adaptation to climate change is a multifaceted challenge that requires collaborative action among various stakeholders, including governments, communities, civil society organizations, and the private sector. This collaboration is essential for sharing resources, understanding the challenges and opportunities, and ensuring ownership of adaptation initiatives. By working together, stakeholders can address equity and fairness concerns, ensure robust decision-making processes, and promote transparency in CSA initiatives.

Bankable Investments in CSA. Investing in CSA requires careful consideration of financial and economic risks and the potential for solid financial and economic returns. CSA projects need to be "bankable," meaning they should attract investors and generate positive financial and economic outcomes. Designing synergistic CSA practices that work together effectively, taking advantage of changing climate conditions, and ensuring cost-effectiveness are crucial for bankable CSA investments. Promoting market solutions, scalability, and appropriate checks and balances are also important considerations for providing the financial viability and sustainability of CSA investments.

Roadmap for Collaborative Action. Effective collaborative action requires a clear roadmap that outlines the steps involved in working together towards shared goals. This roadmap should include identifying shared goals, mapping stakeholders, establishing rules of engagement, developing action plans, and building trust among stakeholders. Open and transparent decision-making, regular feedback mechanisms, and the integration of lessons learned are essential for effective collaboration.

Promoting CSA requires a rich ecosystem of end-to-end solutions that work together and evolve organically. This means that CSA should not be seen as a one-size-fits-all approach but rather as a flexible and adaptable set of practices and technologies tailored to different regions and communities' specific needs and contexts. Avoiding undue emphasis on incentives and designing practical approaches are essential for long-term success. Local governments and communities play a crucial role in CSA implementation, and their capacity building is necessary. Successful business models, pilot demonstrations, and hands-on training are proven ways of building capacity.

6.5 Recommendations

Effective policy and institutional support for CSA offers numerous benefits. Incentivising farmers and providing resources increases the adoption of CSA practices, leading to enhanced resilience to climate change impacts and improved food security. Furthermore, CSA practices contribute to climate change mitigation by reducing greenhouse gas emissions and promoting carbon sequestration. Ultimately, CSA adoption leads to increased productivity, improved incomes, and enhanced food security for farmers and their communities. In general, by creating an enabling environment for CSA adoption, policymakers and institutions can play a crucial role in promoting sustainable agriculture and building resilience to climate change.

Policies and institutions play a crucial role in creating an environment that enables adopting climate-smart agriculture (CSA) practices. Supportive policies and effective institutions can incentivise farmers to adopt CSA, provide the necessary resources and technical support, and facilitate stakeholder collaboration and knowledge-sharing. Key recommendations emerging from the workshop are:

Policy Recommendations

(1) Promote Sustainable Land Use: Implement policies that encourage sustainable land-use practices, such as conservation agriculture, agroforestry, and organic farming, to reduce deforestation and land degradation.

(2) Strengthen Land Tenure Security: Provide farmers with secure land ownership or user rights to encourage investment in sustainable land management practices.
(3) Support CSA Practices: Develop policies that support the adoption of CSA practices, such as providing incentives for using efficient irrigation systems, promoting the use of biochar, and supporting organic agriculture.
(4) Mainstream Climate Change Adaptation: Integrate climate change considerations into agricultural policies, plans, and programs to ensure that agricultural development is resilient to the impacts of climate change.

Investment Recommendations

(1) **Research and Development:** Invest in research and development to identify and promote climate-smart agricultural technologies and practices appropriate for the highlands' specific biophysical and socioeconomic conditions.
(2) **Infrastructure:** Invest in infrastructure, such as irrigation systems, water storage facilities, and rural roads, to support sustainable agricultural development in the highlands.
(3) **Technology:** Promote digital technologies, such as traceability systems, remote sensing, and precision agriculture, to improve the efficiency and sustainability of agricultural value chains.

Capacity Building and Knowledge Sharing Recommendations

(1) **Training Programs:** Develop and implement training programs for farmers, local government officials, and other stakeholders on climate change adaptation, CSA practices, and digital technologies.
(2) **Extension Services:** Strengthen agricultural extension services to provide farmers with timely and accurate information on climate-smart farming practices and market opportunities.
(3) **Knowledge Sharing:** Promote knowledge sharing and collaboration among farmers, researchers, policymakers, and other stakeholders to accelerate the adoption of CSA practices and enhance the resilience of highland agricultural systems.

6.6 The Way Forward for Scaling Up CSA in Highlands

The future of climate-smart agriculture (CSA) in the highlands depends on a multifaceted approach combining policy support, research and development investment, capacity building, and knowledge sharing. Promoting sustainable land-use practices, strengthening land tenure security, supporting the adoption of CSA practices, and mainstreaming climate change adaptation into agricultural policies and programs are essential to achieving sustainable and resilient farming systems in the highlands. Investing in research and development, infrastructure, and technology can further enhance these systems' productivity, resilience, and sustainability.

Capacity building and knowledge sharing are crucial for empowering farmers, communities, and institutions to implement CSA practices and adapt to the impacts of climate change effectively. By working together, stakeholders can create a more sustainable and resilient future for agriculture in the highlands of the GMS countries.

Overall, scaling up CSA practices and technologies presents both challenges and opportunities. Overcoming challenges and working on opportunities s can facilitate the scaling up of CSA and contribute to a more sustainable and resilient future for agriculture in the face of climate change.

Challenges

The adoption of CSA in highland regions faces several key challenges that hinder widespread implementation. One of the most significant barriers is the high initial cost associated with climate-smart technologies, such as precision irrigation systems, agroforestry setups, and resilient seed varieties. Smallholder farmers often operate on limited financial resources and find these investments prohibitive. Compounding this issue is the lack of access to financing, as many farmers struggle to obtain loans, grants, or subsidies to support their transition to CSA.

Resistance to change remains a significant hurdle, as traditional farming methods are deeply embedded in rural communities. Many farmers hesitate to adopt new techniques due to uncertainty about returns, risk aversion, and limited understanding of CSA benefits. Additionally, knowledge gaps present a significant challenge, as many farmers lack access to training and extension services that could help them implement CSA effectively. Farmers may struggle to optimize CSA practices and achieve the intended benefits without adequate technical support.

Financial constraints are a significant hurdle, as the initial investment costs for CSA technologies, such as irrigation systems or precision agriculture tools, can be high. This particularly challenges smallholder farmers in developing countries with limited capital access.

Another challenge is the need for technical knowledge and capacity. Implementing and managing CSA practices often require specific skills and understanding that farmers and local communities may need to acquire. This highlights the importance of training and knowledge transfer initiatives to support CSA adoption.

Institutional and policy barriers can also hinder the scaling up of CSA. The lack of supportive policies, inadequate infrastructure, and weak institutions can create an unsupportive environment for CSA adoption. Addressing these institutional and policy gaps is crucial for creating an enabling environment for CSA.

Market access and value chains pose another challenge. Limited market access and poorly developed value chains can discourage farmers from investing in CSA practices. If farmers cannot sell their products at fair prices, they may be less inclined to adopt CSA. Developing efficient and accessible markets for CSA products is essential for encouraging wider adoption.

Finally, the uncertainties associated with climate change impacts, such as changing rainfall patterns and increased frequency of extreme weather events, can make planning and implementing long-term CSA strategies challenging. Building flexibility and adaptive capacity into CSA planning can help address these uncertainties and ensure the long-term sustainability of CSA initiatives.

Opportunities

Despite these challenges, several opportunities exist to support the scaling up of CSA in highland regions. One major avenue is the introduction of financial incentives and support mechanisms, such as government subsidies, tax incentives, and grants designed to reduce the financial burden on smallholder farmers. Community-based training and capacity-building programs also present a valuable opportunity, enabling farmers to learn from each other through farmer-to-farmer networks and extension programs that provide hands-on demonstrations of CSA benefits.

Success stories and demonstration farms can further encourage adoption by showcasing real-world examples where CSA has led to increased yields, improved soil health, and greater economic stability. Additionally, strengthening market linkages for CSA products can improve farmers' profitability and serve as a strong incentive for adoption. When farmers have access to reliable markets that reward sustainable practices, they are more likely to invest in CSA technologies and methods.

DTechnological advancements like sensors, drones, and artificial intelligence are revolutionising agriculture. These technologies offer new possibilities for precision agriculture, data-driven decision-making, and efficient resource management. By embracing these advancements, farmers can optimise their practices and enhance their productivity while minimising environmental impact.

Furthermore, there is a growing consumer demand for sustainably produced food. Consumers are increasingly interested in the origin and production methods of their food, creating an increasing market for sustainably and ethically sourced agricultural products. This trend presents an opportunity for farmers who adopt CSA practices to access premium markets and secure better product prices. Farmers can improve their livelihoods and contribute to a more sustainable food system by meeting this demand.

Increased investment in climate finance also presents an opportunity for scaling up CSA. As the importance of climate action gains global recognition, there is a growing investment in climate finance, including funding for CSA projects in developing countries. This increased funding can provide farmers with the financial resources they need to adopt CSA technologies and practices, overcoming the economic barriers that often hinder adoption.

Finally, partnerships and collaboration play a crucial role in scaling up CSA. Collaboration among farmers, researchers, policymakers, businesses, and civil society organisations can facilitate knowledge sharing, innovation, and the scaling up of CSA practices. By working together, these stakeholders can create an enabling environment for CSA adoption, sharing knowledge, best practices, and resources to accelerate the transition to sustainable and resilient agricultural systems.

Integrating CSA into Local Development Planning

For CSA to be effectively scaled up and sustained in highland regions, it is essential to integrate CSA principles into municipal and regional development plans. Local authorities are critical in facilitating CSA adoption by aligning agricultural policies with broader climate adaptation and rural development strategies. Key actions include:

(1) Mainstreaming CSA into Local Government Policies
- CSA should be embedded in municipal land use and zoning plans to promote sustainable agricultural practices.
- Developing regulatory frameworks that incentivize the adoption of CSA through tax benefits, subsidies, and investment grants.
- Ensuring CSA is incorporated into local environmental conservation and watershed management strategies.

(2) Strengthening Policy Recommendations for CSA Adoption
- Enhancing national and provincial policies to support CSA as a core component of climate adaptation and food security strategies.
- Establishing clear guidelines for local governments to integrate CSA into their annual agricultural development plans.
- Promoting participatory planning approaches where farmers and community stakeholders contribute to CSA policy formulation.

(3) Institutional Support and Governance for CSA Implementation
- Building the capacity of local agricultural offices to provide CSA training, extension services, and technical assistance to farmers.
- Encouraging interdepartmental coordination between agriculture, environment, and water resource agencies to create a cohesive CSA strategy.
- Establishing dedicated funding streams within municipal budgets for CSA initiatives and farmer support programs.

Integrating CSA into local development planning ensures long-term adoption and sustainability, making climate-resilient agriculture a cornerstone of highland economic and environmental policies. By embedding CSA in governance structures, policymakers can create an enabling environment encouraging widespread adoption, improving rural livelihoods, and enhancing climate resilience in highland communities.

Strategies for Upscaling

Effectively scaling up CSA requires a multi-pronged approach that addresses the challenges and capitalises on the opportunities. For this reason, a combination of targeted strategies must be employed. Government-led initiatives should prioritize dedicated funding streams and subsidy programs to make CSA more financially accessible for smallholder farmers. Strengthened extension services will also be critical, ensuring farmers receive continuous training and technical assistance beyond the initial adoption phase. Public-private partnerships (PPPs) can be crucial in expanding access to CSA resources by fostering collaboration between governments, NGOs, research institutions, and private sector actors. Adaptive policy frameworks should also be developed to align CSA adoption strategies with broader agricultural and environmental policies. Policymakers can facilitate widespread adoption and long-term sustainability by creating an enabling regulatory environment and integrating CSA into local and national planning.

One crucial strategy is to provide farmers with financial incentives and support, such as subsidies or low-interest loans, to help them overcome the financial barriers to adopting CSA technologies. By reducing the initial investment costs, farmers are more likely to invest in CSA practices and technologies, leading to broader adoption.

Capacity building and knowledge transfer are equally important. Investing in training programs, farmer field schools, and knowledge-sharing platforms can enhance farmers' and local communities' technical knowledge and capacity to implement CSA practices effectively. When farmers are equipped with the necessary skills and expertise, they are more likely to adopt and sustain CSA practices, leading to improved outcomes.

Strengthening institutions and policies is also crucial for creating an enabling environment for CSA adoption. Supportive policies that promote sustainable land management, water conservation, and climate change adaptation can incentivise farmers to adopt CSA practices. Additionally, empowering institutions to provide effective extension services, technical assistance, and market access support can facilitate the scaling up of CSA.

Market development and value chain enhancement are essential for incentivising farmers to adopt CSA practices. Developing efficient and sustainable value chains, creating market linkages, and promoting certification schemes for sustainably produced agricultural products can enable farmers to access premium markets and secure better product prices. This can make a positive feedback loop, encouraging more farmers to adopt CSA practices and contribute to a more sustainable agricultural system.

Finally, collaborative action and knowledge sharing are crucial for accelerating the adoption and scaling up of CSA practices. Fostering collaboration among stakeholders, including farmers, researchers, policymakers, businesses, and civil society organisations, can facilitate knowledge sharing, innovation, and the scaling up of CSA practices. By working together, these stakeholders can create a more supportive environment for CSA adoption, share best practices, and overcome challenges collectively.

By addressing the challenges and capitalising on the opportunities, we can accelerate the adoption and scaling up of CSA practices and technologies, contributing to a more sustainable and resilient future for agriculture in the face of climate change in the Nan Province in particular and Asia in general.