Japan Fund for Prosperous and Resilient Asia and the Pacific

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ADB TA-9993 THA: Climate Change Adaptation in Agriculture for Enhanced Recovery and Sustainability of Highlands

Climate Smart Agriculture in Highlands

A Compendium of Practices for Sustainable Watershed Management

Asian Institute of Technology

NIPPON KOEI

TEAM GROUP

TA 9993-THA: Climate Change Adaptation in Agriculture for Enhanced Recovery and Sustainability of Highlands

Knowledge Product

Climate Smart Agriculture in Highlands: A Compendium of Practices for Sustainable Watershed Management

August 2024

Project Name: Climate Change Adaptation in Agriculture for Enhanced Recovery and Sustainability of Highlands
Project No.: TA 9993-THA
Recipient: Asian Development Bank (ADB) and Office of Agricultural Economics (OAE)
Document Type: Knowledge Product – KP10
Version: 1
Date: 06 August 2024
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Preface

This compendium of climate-smart agriculture (CSA) practices for highland regions is one of the significant knowledge products of the technical assistance project, ADB TA-9993 THA: Climate Change Adaptation in Agriculture for Enhanced Recovery and Sustainability of Highlands, financed by the Japan Fund for Prosperous and Resilient Asia and the Pacific (JFPR) through the Asian Development Bank to support sustainable and resilient agricultural development in highlands in Thailand in particular, and Asia and the Pacific in general, particularly in the face of the growing challenges posed by climate change.

Highland regions are home to diverse ecosystems, unique cultures, and millions of people whose livelihoods depend on agriculture. These regions are also particularly vulnerable to the impacts of climate change, such as changes in temperature and precipitation patterns, increased frequency and intensity of extreme weather events, and the spread of pests and diseases. Climate change threatens to undermine decades of development progress in these regions, exacerbating poverty, food insecurity, and environmental degradation.

Climate-smart agriculture offers a pathway to address these challenges by transforming agricultural systems to make them more resilient, productive, and sustainable. CSA practices can help farmers adapt to the changing climate, mitigate greenhouse gas emissions, and improve their livelihoods. This compendium provides a comprehensive overview of various CSA practices that can be applied in highland regions, ranging from soil and water conservation to crop diversification, integrated pest management, livestock management, agroforestry, renewable energy, and climate information services.

The practices presented in this compendium are not merely theoretical concepts, but proven solutions successfully implemented in various highland regions across Asia and the Pacific. They represent the ingenuity and resilience of farmers, researchers, and development practitioners working together to build a more sustainable and climate-resilient future for highland agriculture.

Contents

Abbreviations

ADB	Asian Development Bank
CA	Conservation agriculture
CIS	Climate Information Services
CSA	Climate-Smart Agriculture
GHG	Greenhouse Gases
GPS	Global Positioning System
IPM	Integrated Pest Management
KP	Knowledge Product
OAE	Office of Agricultural Economics
PA	Precision agriculture
RWH	Rainwater harvesting
SPIS	Solar-powered irrigation systems
TA	Technical Assistance

1. Introduction

1.1 Background

Climate change is a global challenge with far-reaching consequences for agriculture, particularly in vulnerable regions such as the highlands. These regions are characterized by unique climatic conditions, fragile ecosystems, and often marginalized communities whose livelihoods depend heavily on agriculture. The increasing frequency and intensity of extreme weather events, such as droughts, floods, and heatwaves, coupled with changes in temperature and precipitation patterns, pose significant threats to agricultural productivity, food security, and the well-being of highland communities.

In response to these challenges, climate-smart agriculture (CSA) has emerged as a holistic approach to transforming agricultural systems to make them more resilient, productive, and sustainable in the face of climate change. CSA encompasses many practices and technologies that address the interconnected challenges of food security, climate change adaptation, and mitigation. By adopting CSA practices, farmers in highland regions can adapt to the changing climate and contribute to global efforts to reduce greenhouse gas emissions and promote sustainable development.

Bua Yai Subdistrict, Na Noi District, Nan Province: Huai Pha Lat Reservoir. Source: Authors.

1.2 What is Climate-Smart Agriculture (CSA)?

CSA is a landscape management strategy encompassing cropland, livestock, forests, and fisheries. Its three primary objectives are to:

(1) **Increase Productivity**: Sustainably enhance agricultural yields and incomes to improve food security and livelihoods.
(2) **Enhance Resilience**: Mitigate vulnerability to climate change impacts like droughts, floods, and extreme temperatures while strengthening adaptive capacity.
(3) **Reduce Emissions**: Decrease agricultural greenhouse gas emissions and promote carbon sequestration in soil and biomass.

1.3 CSA Practices for Highland Environments

Given the specific conditions of highland regions, CSA often involves a combination of practices that include:

(1) Climate-Smart Water Management
- Solar-powered irrigation system
- Keyline approach
- Rainwater harvesting

(2) Climate-Adaptive Soil Management and Organic Farming
- Terracing
- Mulching and soil cover
- Biochar
- Contour farming
- Traditional organic composting

(3) Climate-Smart Crop Management
- Crop rotation
- Cover cropping
- Conservation agriculture
- Crop diversification
- Growing drought-tolerant crops

(4) Digital Technology-Based Solutions
- Precision agriculture
- Climate information services

(5) Livestock Management
- Livestock integration
- Rotational grazing
- Silvopasture

(6) Other Highland CSA Practices
- Agroforestry
- Pest management
- Windbreaks

1.4 Benefits of CSA in Highlands

Implementing CSA in highland regions yields numerous benefits:

(1) **Improved Food Security:** Increased yields and diversified crops enhance food availability, particularly during climate stress.
(2) **Increased Income:** Diversified income streams from crops, livestock, and agroforestry products provide greater financial stability for farmers.
(3) **Enhanced Resilience:** CSA practices protect soil and water resources, making agriculture more resilient to climate change impacts.
(4) **Reduced Emissions:** Sustainable land management practices sequester carbon in the soil and biomass, contributing to climate change mitigation.
(5) **Ecosystem Services:** CSA practices help protect biodiversity, improve water quality, and provide other environmental benefits.

1.5 Limitations and Adaptability

While CSA offers promising solutions, it is essential to consider potential limitations and the need for adaptability:

(1) **Initial Investment:** Some CSA practices may require upfront investments in infrastructure or training.
(2) **Technical Knowledge:** Farmers may need access to technical knowledge and support to implement CSA practices effectively.
(3) **Site-Specificity:** CSA practices must be tailored to each highland region's specific climatic, soil, and socio-economic conditions.

In conclusion, climate-smart agriculture presents a viable pathway for sustainable agricultural development in highland regions. By implementing a combination of practices adapted to the unique conditions of each area, farmers can increase productivity, enhance resilience, and reduce emissions, contributing to both local livelihoods and global climate goals.

2. Gender-Responsive CSA Strategies

2.1 Background

Women play a central role in highland agriculture, often shouldering most labor-intensive tasks such as planting, weeding, and harvesting. They also play a crucial role in managing household food security and nutrition. However, women in highland regions often face significant gender-based constraints, such as limited access to land, credit, information, and decision-making power. These constraints can hinder their ability to adapt to climate change and adopt climate-smart agricultural (CSA) practices.

Gender-responsive CSA recognizes the different roles, needs, and priorities of women and men in agriculture and seeks to address gender inequalities to ensure that women and men benefit equally from CSA interventions. By empowering women and promoting their participation in decision-making, gender-responsive CSA can enhance the effectiveness and sustainability of climate change adaptation and mitigation efforts in highland regions.

2.2 Challenges

Several challenges hinder the development and adoption of gender-responsive CSA practices in highlands:

(1) **Gender Norms and Stereotypes:** Traditional gender norms and stereotypes often limit women's access to resources and opportunities in agriculture. These norms can restrict women's mobility, decision-making power, and participation in agricultural training and extension services.

(2) **Unequal Access to Resources:** Women in highland regions often have limited access to land, credit, technology, and information, which are essential for adopting CSA practices. This unequal access can perpetuate gender inequalities and hinder women's ability to adapt to climate change.

(3) **Limited Participation in Decision-Making:** Women are often excluded from decision-making processes related to agriculture at the household and community levels. This can lead to the neglect of women's needs and priorities in agricultural planning and implementation.

(4) **Climate Change Impacts:** Climate change disproportionately affects highland women due to their reliance on natural resources and limited adaptive capacity. Droughts, floods, and other extreme weather events can exacerbate existing gender inequalities and increase women's vulnerability.

2.3 Strategies

To overcome these challenges and promote gender-responsive CSA in highlands, several strategies can be adopted:

(1) **Empowering Women:** Empowering women through access to education, training, and information can enhance their knowledge and skills in CSA practices. This can also boost their confidence and enable them to participate more actively in decision-making processes.

(2) **Addressing Gender Norms:** Challenging traditional gender norms and stereotypes is crucial for promoting gender equality in agriculture. This can be achieved through awareness-raising campaigns, community dialogues, and gender-sensitive training programs.

(3) **Improving Access to Resources:** Ensuring women's equal access to land, credit, technology, and information is essential for their participation in CSA. This can be achieved through gender-sensitive policies, programs, and financial mechanisms.
(4) **Promoting Women's Leadership:** Encouraging women's leadership and participation in decision-making processes at all levels can ensure that their needs and priorities are considered in agricultural planning and implementation.
(5) **Integrating Gender into Climate Change Policies and Programs:** Mainstreaming gender considerations into climate change policies and programs can ensure that women are not left behind in adaptation and mitigation efforts.

***Bua Yai Subdistrict, Na Noi District, Nan Province**: Woman farmer talking to the TA Consultant experts regarding challenges, strategies, and opportunities regarding CSA. Source: Authors.*

2.4 Opportunities

The development and adoption of gender-responsive CSA practices in highlands present several opportunities:

(1) **Enhanced Resilience:** Empowering women and addressing gender inequalities can strengthen the resilience of highland communities to climate change. Women's knowledge and skills in sustainable agriculture and natural resource management can be leveraged to develop and implement effective adaptation strategies.
(2) **Improved Food Security:** By increasing women's access to resources and decision-making power, gender-responsive CSA can enhance agricultural productivity and food security for highland households and communities.
(3) **Sustainable Development:** Gender-responsive CSA can contribute to sustainable development by promoting gender equality, empowering women, and ensuring that the benefits of CSA are equitably shared.
(4) **Climate Change Mitigation:** Women's participation in CSA can lead to adopting more sustainable agricultural practices, such as agroforestry and conservation agriculture, which can contribute to climate change mitigation by sequestering carbon and reducing greenhouse gas emissions.

By investing in gender-responsive CSA, we can unlock the full potential of women in highland agriculture, build more resilient communities, and contribute to a more sustainable and equitable future for all.

3. Climate-Smart Water Management

3.1 Solar-Powered Irrigation Systems

3.1.1 Background

Solar-powered irrigation systems (SPIS) utilize solar energy to pump water for irrigation. This technology is particularly relevant in highland regions, where access to electricity may be limited, and water resources are often scarce. SPIS offers a sustainable and cost-effective solution for providing irrigation water, especially in remote areas where conventional energy sources are not readily available. By harnessing solar energy, SPIS can improve agricultural productivity, enhance water use efficiency, and reduce reliance on fossil fuels.

Source: https://solarquarter.com/2023/06/30/philippines-department-of-agriculture-implements-solar-powered-irrigation-systems-in-leyte/

3.1.2 Innovative Features

Recent advancements in solar technology have led to the development of innovative features in SPIS, making them more efficient, reliable, and accessible to highland farmers. Some of these innovative features include:

(1) Advanced photovoltaic panels: High-efficiency solar panels can generate more electricity from the same amount of sunlight, reducing the size and cost of the system.
(2) Smart irrigation controllers: Controllers that use weather data and soil moisture sensors to optimize irrigation schedules, minimizing water waste and maximizing crop yields.
(3) Mobile monitoring and control: These systems allow farmers to monitor and control their irrigation systems remotely using smartphones or other mobile devices.
(4) Hybrid systems: Combining solar power with other energy sources, such as wind or hydropower, to ensure a reliable water supply even during periods of low sunlight.

3.1.3 Contribution to Productivity Improvement

SPIS can contribute to productivity improvement in highlands in several ways:

(1) Increased water availability: SPIS can provide a reliable source of irrigation water, even in remote areas with limited access to electricity or surface water.
(2) Improved water use efficiency: Using drip irrigation or other water-saving technologies, SPIS can significantly improve water use efficiency, reducing water waste and maximizing crop yields.
(3) Extended growing seasons: SPIS can enable farmers to extend their growing seasons by providing irrigation during dry periods, increasing agricultural production.
(4) Enhanced crop quality: Consistent and timely irrigation through SPIS can improve crop quality, leading to higher market prices and increased farmer income.

Bua Yai Subdistrict, Na Noi District, Nan Province*: Solar-powered irrigation system implementation at the field. Source: Authors.*

3.1.4 Contribution to Climate Resilience

SPIS can enhance climate resilience in highlands by:

(1) Reducing vulnerability to drought: SPIS can provide a reliable source of irrigation water during droughts, reducing crop losses and ensuring food security.
(2) Adapting to changing rainfall patterns: SPIS can supplement rainfall during periods of low precipitation, ensuring adequate crop water supply.
(3) Mitigating the impact of extreme weather events: SPIS can help to reduce the effects of extreme weather events, such as floods or heatwaves, by providing irrigation water to stressed crops.

3.1.5 Contribution to Greenhouse Gas Mitigation

SPIS can contribute to greenhouse gas mitigation by:

(1) Reducing reliance on fossil fuels: SPIS replaces diesel or gasoline-powered pumps, reducing greenhouse gas emissions from agricultural activities.
(2) Promoting renewable energy use: SPIS utilizes solar energy, a clean and renewable energy source, contributing to the transition towards a low-carbon economy.

3.1.6 Social Impact

SPIS can have positive social impacts in highlands by:

(1) Improving livelihoods: SPIS can increase agricultural productivity and income, leading to improved livelihoods for farmers and their families.
(2) Enhancing food security: SPIS can contribute to food security by ensuring a reliable water supply for crops, even during droughts.
(3) Empowering women: SPIS can empower women by reducing their workload associated with manual irrigation and providing them with opportunities for income generation.

3.1.7 Economic Impact

SPIS can have positive economic impacts in the highlands by:

(1) Reducing irrigation costs: SPIS can significantly reduce irrigation costs by eliminating the need for expensive fossil fuels.
(2) Increasing crop yields: SPIS can improve crop yields through consistent and timely irrigation, leading to higher incomes for farmers.
(3) Creating employment opportunities: SPIS can generate employment opportunities in installing, maintaining, and operating irrigation systems.

3.1.8 Other Ecosystem Benefits

SPIS can provide a range of other ecosystem benefits in highlands, including:

(1) Groundwater recharge: By using surface water sources, SPIS can help to recharge groundwater aquifers, ensuring long-term water availability.
(2) Reduced soil salinity: SPIS can help to reduce soil salinity by providing adequate irrigation water to leach out salts from the root zone.
(3) Improved water quality: SPIS can improve water quality by reducing the use of agrochemicals and preventing soil erosion.

3.1.9 Disadvantages and Tradeoffs, if any

SPIS may have some disadvantages and tradeoffs, including:

(1) High initial investment costs: The initial investment cost of SPIS can be high, especially for small-scale farmers. However, government subsidies and innovative financing models can help to overcome this barrier.
(2) Maintenance requirements: SPIS requires regular maintenance to ensure optimal performance and longevity.
(3) Land requirements: SPIS requires a suitable land area for installing solar panels, which may be limited in some highland areas.

3.1.10 Other Information

SPIS is a promising CSA practice that can transform agriculture in highlands by providing a sustainable and reliable source of irrigation water. It is a scalable technology that can be adapted to different farm sizes and water needs. The success of SPIS depends on proper system design, installation, and maintenance, as well as access to financing and technical support.

***Bua Yai Subdistrict, Na Noi District, Nan Province**: Water system for solar irrigation. Source: Authors.*

3.2 Keyline Approach

3.2.1 Background

The Keyline approach is a landscape design and water management system developed in the 1950s by Australian farmer P.A. Yeomans. It is based on the understanding that water is the key to soil fertility and land productivity. The Keyline approach involves designing and managing landscapes to slow, spread, and sink rainwater into the soil, thereby maximizing water infiltration and retention. This approach is particularly relevant in highland regions, where steep slopes, thin soils, and variable rainfall patterns pose challenges for agriculture. By enhancing water management and soil health, the Keyline approach can improve agricultural productivity, increase resilience to drought and erosion, and contribute to climate change mitigation.

Source: https://images.app.goo.gl/1RAULs7yVqLnRU2r9

3.2.2 Innovative Features

The Keyline approach incorporates several innovative features that distinguish it from conventional land management practices:

(1) **Keyline design:** Identifying key points and contour lines on the landscape to design a system of interconnected swales and ponds that capture and distribute rainwater.
(2) **Keyline ploughing:** A specialized plough creates shallow furrows along the contour lines, slowing water flow and promoting infiltration.
(3) **Strategic grazing management:** Integrating livestock grazing into the Keyline system improves soil health, promotes vegetation growth, and enhances carbon sequestration.
(4) **Holistic land management:** Considering the entire landscape as an interconnected system and managing it for multiple benefits, including agricultural productivity, ecological health, and climate resilience.

Bua Yai Subdistrict, Na Noi District, Nan Province*: Keyline ploughing for maximizing water infiltration and retention. Source: Authors.*

3.2.3 Contribution to Productivity Improvement

The Keyline approach can contribute to productivity improvement in highlands in several ways:

(1) **Increased water infiltration:** Keyline design and ploughing help to improve water infiltration into the soil, making more water available for plant growth and reducing runoff.
(2) **Improved soil moisture retention:** By slowing down water flow and promoting infiltration, the Keyline approach can improve soil moisture retention, reduce drought risk, and enhance crop yields.
(3) **Enhanced soil fertility:** Keyline practices, such as strategic grazing management and the use of cover crops, can improve soil fertility by increasing organic matter content, nutrient cycling, and microbial activity.
(4) **Reduced soil erosion:** Keyline design and ploughing help minimize soil erosion by slowing down water flow and trapping sediment, thereby conserving topsoil and nutrients.

3.2.4 Contribution to Climate Resilience

The Keyline approach can enhance climate resilience in highlands by:

(1) **Drought mitigation:** By improving water infiltration and retention, the Keyline approach can help to mitigate the effects of drought and ensure a more reliable water supply for crops and livestock.
(2) **Flood mitigation:** Keyline design can help to slow down and spread-out floodwaters, reducing their destructive potential and protecting downstream areas.
(3) **Erosion control:** Keyline practices can help to control soil erosion caused by heavy rainfall and extreme weather events, which are becoming more frequent and intense due to climate change.
(4) **Soil health improvement:** The Keyline approach can improve soil health by increasing organic matter content, nutrient cycling, and microbial activity, making soils more resilient to climate stressors.

3.2.5 Contribution to Greenhouse Gas Mitigation

The Keyline approach can contribute to greenhouse gas mitigation by:

(1) **Increasing soil carbon sequestration:** Keyline practices, such as strategic grazing management and the use of cover crops, can increase soil organic matter content, which can sequester carbon and reduce carbon dioxide emissions.
(2) **Reducing emissions from land degradation:** By improving soil health and preventing erosion, the Keyline approach can reduce greenhouse gas emissions associated with land degradation.

3.2.6 Social Impact

The Keyline approach can have positive social impacts in the highlands by:

(1) **Improving livelihoods:** The Keyline approach can increase agricultural productivity and income, leading to improved livelihoods for farmers and their families.
(2) **Enhancing food security:** The Keyline approach can improve food security in highland communities by improving water management and soil fertility.
(3) **Promoting community engagement:** Keyline projects often involve community participation in planning, implementation, and management, fostering social cohesion and empowerment.

3.2.7 Economic Impact

The Keyline approach can have positive economic impacts in the highlands by:

(1) **Increasing agricultural productivity:** The Keyline approach can increase crop yields and livestock productivity, resulting in higher incomes for farmers.
(2) **Reducing input costs:** By improving water management and soil fertility, the Keyline approach can reduce the need for irrigation, fertilizers, and pesticides, lowering input costs for farmers.
(3) **Creating employment opportunities:** Keyline projects can generate employment opportunities by designing, implementing, and maintaining keyline systems.

3.2.8 Other Ecosystem Benefits

The Keyline approach can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved biodiversity:** Keyline systems can create diverse habitats that support a variety of plant and animal species.
(2) **Enhanced water quality:** By reducing erosion and improving water infiltration, the Keyline approach can enhance water quality in rivers and streams.
(3) **Increased groundwater recharge:** Keyline systems can help to recharge groundwater aquifers, ensuring long-term water availability.

3.2.9 Disadvantages and Tradeoffs, if any

The Keyline approach may have some disadvantages and tradeoffs, including:

(1) **Initial investment costs:** Implementing a Keyline system can require significant initial investment in design, earthworks, and infrastructure.
(2) **Technical expertise:** Designing and implementing a Keyline system requires technical expertise and knowledge of landscape processes.
(3) **Maintenance requirements:** Keyline systems require ongoing maintenance to ensure their effectiveness and prevent erosion.

3.2.10 Other Information

The Keyline approach is a holistic and sustainable land management system that can be adapted to various highland environments and farming systems. It offers a promising solution for addressing the challenges of climate change, water scarcity, and soil degradation in highlands. The success of the Keyline approach depends on careful planning, appropriate design, and ongoing management.

3.3 Rainwater Harvesting

3.3.1 Background

Rainwater harvesting (RWH) is collecting and storing rainwater for various uses, including irrigation, livestock watering, and domestic consumption. It is a simple yet effective technique that has been practiced for centuries in different parts of the world. In the context of climate change, RWH is gaining increasing importance as a climate-smart agricultural (CSA) practice due to its potential to address water scarcity, reduce reliance on groundwater, and improve agricultural productivity. This practice is particularly relevant in highland regions, where rainfall patterns are often erratic, water resources are limited, and the demand for water for agriculture and other purposes is high.

Source: https://msfagriculture.com/2020/06/10/agricultural-practices-save-water/

3.3.2 Innovative Features

Traditional RWH techniques have evolved to incorporate innovative features that enhance their efficiency, sustainability, and adaptability to different highland environments. Some of these innovative features include:

(1) **Rooftop rainwater harvesting:** Collecting rainwater from rooftops and storing it in tanks or cisterns for domestic or agricultural use.
(2) **Surface runoff harvesting:** Capturing rainwater from land surfaces, such as fields or roads, and directing it to storage ponds or reservoirs.
(3) **Micro-catchment rainwater harvesting:** Creating small-scale catchments, such as bunds or pits, to collect rainwater and direct it to crops or trees.
(4) **Subsurface dams:** Constructing underground barriers to capture and store rainwater in the subsoil, providing a source of water for crops during dry periods.
(5) **Fog harvesting:** Collecting water from fog using specialized nets or screens, particularly in highland areas with frequent fog.

3.3.3 Contribution to Productivity Improvement

RWH can contribute to productivity improvement in highlands in several ways:

(1) **Increased water availability:** RWH provides an additional water source for irrigation, especially during dry periods when surface water sources may be limited.
(2) **Improved soil moisture:** RWH can help maintain soil moisture levels, promote healthy plant growth, and increase crop yields.
(3) **Reduced irrigation costs:** Farmers can reduce their reliance on expensive irrigation systems and lower production costs by utilizing rainwater.
(4) **Enhanced crop quality:** Consistent and timely irrigation through RWH can improve crop quality, leading to higher market prices and increased farmer income.

3.3.4 Contribution to Climate Resilience

RWH can enhance climate resilience in highlands by:

(1) **Reducing vulnerability to drought:** RWH provides a buffer against drought by storing rainwater for use during dry periods, ensuring a more reliable water supply for crops and livestock.
(2) **Adapting to changing rainfall patterns:** RWH can help farmers adapt to changing rainfall patterns by capturing and storing rainwater during periods of high rainfall for use during periods of low rainfall.
(3) **Mitigating the impact of extreme weather events:** RWH can help reduce the effects of extreme weather events, such as floods or prolonged dry spells, by providing a water source for crops and livestock.

3.3.5 Contribution to Greenhouse Gas Mitigation

RWH can contribute to greenhouse gas mitigation by:

(1) **Reducing energy consumption:** RWH systems typically require less energy than conventional irrigation systems, reducing greenhouse gas emissions associated with energy production.
(2) **Promoting sustainable water management:** RWH reduces reliance on groundwater, which can help to prevent land subsidence and associated greenhouse gas emissions.

3.3.6 Social Impact

RWH can have positive social impacts in highlands by:

(1) **Improving livelihoods:** RWH can increase agricultural productivity and income, leading to improved livelihoods for farmers and their families.
(2) **Enhancing food security:** RWH can contribute to food security by ensuring a reliable water supply for crops, even during droughts.
(3) **Empowering women:** RWH can reduce the burden on women who are often responsible for collecting water for household and agricultural use.
(4) **Promoting community participation:** RWH projects can involve community participation in planning, construction, and maintenance, fostering social cohesion and empowerment.

3.3.7 Economic Impact

RWH can have positive economic impacts in the highlands by:

(1) **Reducing irrigation costs:** RWH can significantly reduce irrigation costs using free rainwater instead of expensive pumped water.
(2) **Increasing crop yields:** RWH can improve crop yields through consistent and timely irrigation, leading to higher incomes for farmers.
(3) **Creating employment opportunities:** RWH projects can generate employment opportunities in constructing, maintaining, and managing rainwater harvesting systems.

3.3.8 Other Ecosystem Benefits

RWH can provide a range of other ecosystem benefits in highlands, including:

(1) **Groundwater recharge:** RWH can help to recharge groundwater aquifers, ensuring long-term water availability for various uses.
(2) **Reduced soil erosion:** RWH can minimize erosion by slowing down runoff water and promoting infiltration.
(3) **Improved water quality:** RWH can improve water quality by reducing sediment and nutrient runoff from agricultural fields.

3.3.9 Disadvantages and Tradeoffs, if any

RWH may have some disadvantages and tradeoffs, including:

(1) **Initial investment costs:** The initial cost of constructing RWH systems can be high, especially for large-scale projects. However, government subsidies and community-based approaches can help to overcome this barrier.
(2) **Maintenance requirements:** RWH systems require regular maintenance to ensure their effectiveness and prevent contamination of stored water.
(3) **Dependence on rainfall:** RWH systems depend on rainfall, and their effectiveness may be limited during periods of low rainfall.

3.3.10 Other Information

RWH is a versatile and adaptable CSA practice that can be tailored to different highland regions' specific needs and conditions. It can be implemented on a small scale by individual households or on a larger scale through community-based projects. The success of RWH depends on proper system design, construction, maintenance, community participation, and awareness.

4. Climate-Adaptive Soil Management and Organic Farming

4.1 Terracing

4.1.1 Background

Terracing is an ancient agricultural practice that involves creating level platforms on sloping land. These platforms, or terraces, are designed to reduce soil erosion, conserve water, and improve agricultural productivity. Terracing has been used for centuries in different parts of the world, particularly in mountainous regions where steep slopes pose challenges for agriculture. In the context of climate change, terracing is gaining renewed importance as a climate-smart agricultural (CSA) practice due to its potential to address the challenges posed by soil erosion, water scarcity, and extreme weather events.

Source: https://www.worldbank.org/en/results/2018/09/10/climate-smart-productive-landscapes-increase-incomes-and-combat-climate-change-hillside-agriculture-intensification-in-rwanda

4.1.2 Innovative Features

Traditional terracing techniques have evolved to incorporate innovative features that enhance their effectiveness and sustainability. Some of these innovative features include:

(1) **Bench terracing:** Creating wide, level terraces that are suitable for mechanized farming and can accommodate a variety of crops.
(2) **Contour terracing:** Constructing terraces along the contour lines of the slope to minimize soil disturbance and maximize water retention.
(3) **Graded terracing:** Building terraces with a slight inward slope to direct water towards a central drainage channel, preventing waterlogging and erosion.
(4) **Intercropping:** Planting different crops on the same terrace improves soil fertility, reduces pests and disease pressure, and diversifies income sources.

4.1.3 Contribution to Productivity Improvement

Terracing can contribute to productivity improvement in highlands in several ways:

(1) **Reduced soil erosion:** Terraces help to minimize soil erosion by slowing down the flow of water and trapping sediment, thereby conserving topsoil and nutrients.
(2) **Improved water management:** Terraces can capture and retain rainwater, making it available for crop growth and reducing drought risk.
(3) **Enhanced soil fertility:** Terracing can improve soil fertility by reducing nutrient loss through erosion and promoting organic matter accumulation.
(4) **Increased cropping area:** Terracing can convert steep slopes into cultivable land, increasing the area available for agriculture.

4.1.4 Contribution to Climate Resilience

Terracing can enhance climate resilience in highlands by:

(1) **Protecting against soil erosion:** Terraces help to protect against soil erosion caused by heavy rainfall and extreme weather events, which are becoming more frequent and intense due to climate change.
(2) **Conserving water resources:** Terraces can capture and store rainwater, making it available for crop growth during dry periods and reducing the risk of drought.
(3) **Mitigating landslide risk:** Terracing can help to stabilize slopes and reduce the risk of landslides, which can be triggered by heavy rainfall and earthquakes.

4.1.5 Contribution to Greenhouse Gas Mitigation

Terracing can contribute to greenhouse gas mitigation by:

(1) **Increasing soil carbon storage:** Terracing can improve soil organic matter content, increase soil carbon storage, and reduce carbon dioxide emissions.
(2) **Reducing emissions from soil erosion:** Terracing can minimize soil erosion, releasing carbon dioxide and other greenhouse gases into the atmosphere.

4.1.6 Social Impact

Terracing can have positive social impacts in highlands by:

(1) **Improving livelihoods:** Terracing can increase agricultural productivity and income, leading to improved livelihoods for farmers and their families.
(2) **Enhancing food security:** Terracing can contribute to food security by increasing crop yields and reducing the risk of crop failure due to soil erosion and water scarcity.
(3) **Promoting community participation:** Terracing projects can involve participation in planning, construction, and maintenance, fostering social cohesion and empowerment.

4.1.7 Economic Impact

Terracing can have positive economic impacts in highlands by:

(1) **Increasing agricultural productivity:** Terracing can lead to increased crop yields and higher incomes for farmers.
(2) **Creating employment opportunities:** Terracing projects can generate employment opportunities in construction, maintenance, and agricultural production.
(3) **Boosting local economies:** Terracing can stimulate local economies by increasing agricultural production and creating demand for goods and services.

4.1.8 Other Ecosystem Benefits

Terracing can provide a range of other ecosystem benefits in highlands, including:

(1) **Biodiversity conservation:** Terraces can create diverse microhabitats that support a variety of plant and animal species.
(2) **Watershed protection:** Terracing can help regulate water flow, reduce erosion, and improve water quality in watersheds.
(3) **Landscape aesthetics:** Terraces can enhance the aesthetic value of landscapes, making them more attractive for tourism and recreation.

4.1.9 Disadvantages and Tradeoffs, if any

Terracing may have some disadvantages and tradeoffs, including:

(1) **High initial investment costs:** Terracing can be labor-intensive and require significant initial investment costs, which may be a barrier for some farmers.
(2) **Maintenance requirements:** Terraces require regular maintenance to prevent erosion and ensure their effectiveness.
(3) **Potential for waterlogging:** Poorly designed or maintained terraces can lead to waterlogging, damaging crops and reducing yields.

4.1.10 Other Information

Terracing is a well-established and effective CSA practice that can be adapted to various highland environments. It can be implemented on a small scale by individual farmers or on a larger scale through community-based projects. The success of terracing depends on careful planning, appropriate design, and ongoing maintenance.

4.2 Mulching and Soil Cover

4.2.1 Background

Mulching covers the soil surface with organic or inorganic materials. It is a widely used agricultural technique that offers numerous benefits for soil health, crop productivity, and environmental sustainability. In the context of climate change, mulching is considered a climate-smart agricultural (CSA) practice due to its potential to conserve soil moisture, reduce erosion, suppress weeds, and moderate soil temperature. These benefits are significant in highland regions, where soils are often thin, vulnerable to erosion, and exposed to harsh climatic conditions.

Source: https://phys.org/news/2022-09-biodegradable-plastic-mulch-climate-smart-agricultural.html

4.2.2 Innovative Features

Traditional mulching practices have evolved to incorporate innovative features that enhance their effectiveness and adaptability to different highland environments. Some of these innovative features include:

(1) **Living mulches:** Using cover crops or nitrogen-fixing plants as living mulches to improve soil fertility, suppress weeds, and enhance biodiversity.
(2) **Biodegradable mulches:** Utilizing biodegradable materials, such as straw, wood chips, or compost, as mulches that decompose over time and enrich the soil.
(3) **Plastic mulches:** Applying plastic mulches to increase soil temperature, conserve moisture, and suppress weeds, particularly for high-value crops.
(4) **Stone mulches:** Stone mulches in arid highland regions are used to reduce evaporation, moderate soil temperature, and prevent erosion.

4.2.3 Contribution to Productivity Improvement

Mulching can contribute to productivity improvement in highlands in several ways:

(1) **Conserving soil moisture:** Mulches reduce evaporation from the soil surface, conserving moisture and making it available for plant growth, especially during dry periods.
(2) **Suppressing weeds:** Mulches can effectively suppress weed growth, reducing competition for water and nutrients and minimizing the need for herbicides.
(3) **Moderating soil temperature:** Mulches can moderate soil temperature, protecting plant roots from extreme heat or cold and creating a more favorable environment for growth.

(4) **Improving soil fertility:** Organic mulches decompose over time, adding organic matter and nutrients to the soil, enhancing its fertility and promoting healthy plant growth.

4.2.4 Contribution to Climate Resilience

Mulching can enhance climate resilience in highlands by:

(5) **Protecting against soil erosion:** Mulches help to protect against soil erosion caused by heavy rainfall, wind, and runoff, which are common in highland areas.
(6) **Conserving water resources:** Mulches reduce water loss through evaporation, conserving water resources and making crops more resilient to drought.
(7) **Moderating soil temperature:** Mulches can buffer soil temperature fluctuations, protecting plant roots from extreme temperatures and reducing stress.
(8) **Improving soil organic matter:** Mulches can increase soil organic matter content, improve soil structure, water-holding capacity, and nutrient retention, and make soils more resilient to climate stressors.

4.2.5 Contribution to Greenhouse Gas Mitigation

Mulching can contribute to greenhouse gas mitigation by:

(1) **Increasing soil carbon sequestration:** Organic mulches decompose and contribute to soil organic matter, which can sequester carbon and reduce carbon dioxide emissions.
(2) **Reducing nitrous oxide emissions:** Mulches can improve nitrogen use efficiency in the soil, reducing the risk of nitrous oxide emissions from excess nitrogen fertilizer application.
(3) **Minimizing soil disturbance:** Mulching can reduce the need for tillage, which can release carbon dioxide from the soil.

4.2.6 Social Impact

Mulching can have positive social impacts in highlands by:

(1) **Improving livelihoods:** Mulching can increase crop yields and income, leading to improved livelihoods for farmers and their families.
(2) **Enhancing food security:** Mulching can contribute to food security by increasing crop yields and reducing the risk of crop failure due to drought and soil erosion.
(3) **Promoting sustainable agriculture:** Mulching can reduce the reliance on synthetic fertilizers and herbicides, promoting sustainable agricultural practices.

4.2.7 Economic Impact

Mulching can have positive economic impacts in highlands by:

(1) **Reducing input costs:** Mulching can reduce the need for irrigation, herbicides, and fertilizers, lowering input costs for farmers.
(2) **Increasing crop yields:** Mulching can improve soil moisture, temperature, and fertility, leading to increased crop yields and higher incomes for farmers.
(3) **Creating market opportunities:** Mulching materials, such as straw or wood chips, can be sourced locally, creating market opportunities for local producers.

4.2.8 Other Ecosystem Benefits

Mulching can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved soil biodiversity:** Mulches can enhance soil biodiversity by providing habitat for beneficial microorganisms and soil fauna.
(2) **Reduced water pollution:** Mulches can reduce nutrient runoff and soil erosion, improving water quality in rivers and streams.

(3) **Enhanced wildlife habitat:** Mulches can provide habitat and food sources for beneficial insects and other wildlife.

4.2.9 Disadvantages and Tradeoffs, if any

Mulching may have some disadvantages and tradeoffs, including:

(1) **Cost of materials:** Some mulching materials, such as plastic mulches, can be expensive, especially for small-scale farmers.
(2) **Labor requirements:** Applying and maintaining mulches can be labor-intensive, especially for large areas.
(3) **Potential for pest and disease problems:** Some mulching materials, such as organic mulches, can harbor pests and diseases if not properly managed.

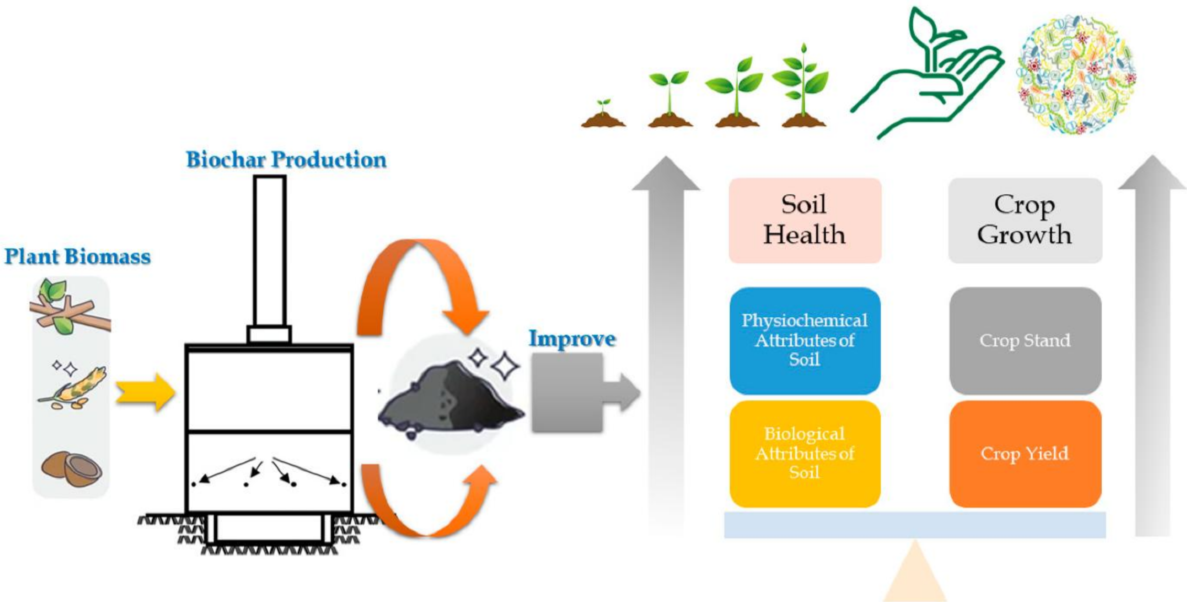
4.2.10 Other Information

Mulching is a simple yet effective CSA practice that can be easily adopted by farmers in the highlands. It can be implemented on a small-scale in-home garden or on a larger scale in commercial farms. The choice of mulching material depends on the specific needs and resources of the farmer and the local environment.

4.3 Biochar

4.3.1 Background

Biochar is a charcoal-like substance produced by heating organic materials, such as wood chips, crop residues, or manure, in a low-oxygen environment. This process, known as pyrolysis, converts organic matter into a stable form of carbon that can be added to soil to improve its fertility, water-holding capacity, and nutrient retention. In the context of climate change, biochar is considered a climate-smart agricultural (CSA) practice due to its potential to sequester carbon, improve soil health, and enhance crop resilience to climate stressors.



Source: https://www.mdpi.com/2223-7747/13/2/166

4.3.2 Innovative Features

While biochar production has been practiced for centuries, innovative approaches have emerged to optimize its production and application in highland agriculture. Some of these innovative features include:

(1) **Tailored feedstock selection:** Selecting locally available and sustainable feedstocks, such as agricultural waste or invasive plant species, for biochar production.
(2) **Optimized pyrolysis conditions:** Adjusting pyrolysis temperature and residence time to produce biochar with specific properties tailored to the needs of highland soils.
(3) **Biochar blends and amendments:** Combining biochar with other soil amendments, such as compost or mineral fertilizers, enhances its effectiveness and addresses specific soil deficiencies.
(4) **Precision application techniques:** Utilizing precision agriculture tools and techniques to apply biochar at variable rates based on soil properties and crop requirements.

Bua Yai Subdistrict, Na Noi District, Nan Province*: Biochar production for application in soils. Source: Authors.*

4.3.3 Contribution to Productivity Improvement

Biochar can contribute to productivity improvement in highlands in several ways:

(1) **Enhanced soil fertility:** Biochar can improve soil fertility by increasing cation exchange capacity, nutrient retention, and microbial activity.
(2) **Improved soil structure:** Biochar can enhance soil structure by increasing porosity, water-holding capacity, and aeration, which are crucial for root growth and nutrient uptake in highland soils.
(3) **Reduced nutrient leaching:** Biochar can minimize nutrient leaching by adsorbing nutrients and releasing them slowly to plants, improving nutrient use efficiency.
(4) **Increased water availability:** Biochar can improve soil water retention, making crops more resilient to drought and reducing the need for irrigation.

4.3.4 Contribution to Climate Resilience

Biochar can enhance climate resilience in highlands by:

(1) **Improving soil water retention:** Biochar can increase soil water-holding capacity, making crops more resilient to drought and reducing the risk of crop failure.
(2) **Enhancing soil fertility:** Biochar can improve soil fertility and nutrient availability, making crops more resilient to nutrients and environmental stressors.
(3) **Promoting soil microbial activity:** Biochar can stimulate beneficial soil microorganisms, which can help suppress plant diseases and improve soil health.

4.3.5 Contribution to Greenhouse Gas Mitigation

Biochar can contribute to greenhouse gas mitigation by:

(1) **Sequestering carbon:** Biochar is a stable form of carbon that can remain in the soil for centuries, effectively removing carbon dioxide from the atmosphere.
(2) **Reducing nitrous oxide emissions:** Biochar can improve nitrogen use efficiency in the soil, reducing the risk of nitrous oxide emissions from excess nitrogen fertilizer application.
(3) **Decreasing methane emissions:** Biochar can alter soil microbial communities, potentially reducing methane emissions from agricultural soils.

4.3.6 Social Impact

Biochar can have positive social impacts in highlands by:

(1) **Improving livelihoods:** Biochar can enhance crop yields and income, leading to improved livelihoods for farmers and their families.
(2) **Enhancing food security:** Biochar can contribute to food security by increasing crop yields and improving soil resilience to climate stressors.
(3) **Promoting sustainable agriculture:** Biochar can reduce the reliance on synthetic fertilizers and pesticides, promoting sustainable agricultural practices.

4.3.7 Economic Impact

Biochar can have positive economic impacts in highlands by:

(1) **Increasing crop yields:** Biochar can improve soil fertility and crop yields, leading to higher incomes for farmers.
(2) **Reducing input costs:** Biochar can lessen the need for fertilizers and pesticides, lowering input costs for farmers.
(3) **Creating market opportunities:** Biochar can be produced and sold as a valuable soil amendment, creating economic opportunities for local communities.

4.3.8 Other Ecosystem Benefits

Biochar can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved soil biodiversity:** Biochar can enhance soil biodiversity by providing a habitat for beneficial microorganisms and soil fauna.
(2) **Reduced soil erosion:** Biochar can improve soil structure and aggregation, reducing the risk of soil erosion.
(3) **Enhanced water quality:** Biochar can reduce nutrient runoff and improve water infiltration, improving water quality in rivers and streams.

4.3.9 Disadvantages and Tradeoffs, if any

Biochar may have some disadvantages and tradeoffs, including:

(1) **Production costs:** Biochar production can be energy-intensive and require specialized equipment, which may be a barrier for some farmers.
(2) **Potential for contamination:** Biochar produced from contaminated feedstocks can introduce pollutants into the soil.
(3) **Limited research on long-term effects:** While the short-term benefits of biochar are well-documented, more research is needed on its long-term effects on soil health and crop productivity.

4.3.10 Other Information

Biochar is a versatile and promising CSA practice that can be adapted to different highland environments and farming systems. It can be produced from various locally available feedstocks and applied using other methods, depending on the specific needs and resources of the farmer. The success of biochar depends on proper production, application, and management practices.

4.4 Contour Farming

4.4.1 Background

Contour farming is a soil and water conservation practice that involves ploughing and planting crops along the contour lines of a slope. This practice is particularly relevant in highland regions, where steep slopes and heavy rainfall can lead to severe soil erosion and water loss. By following the land's natural contours, contour farming reduces the velocity of runoff water, allowing it to infiltrate into the soil and minimizing soil erosion. This practice can improve soil moisture retention, enhance soil fertility, and increase crop yields, making it a valuable climate-smart agricultural (CSA) practice for highlands.

Source: https://daily.sevenfifty.com/the-benefits-of-contour-farming-in-a-changing-climate/

4.4.2 Innovative Features

While contour farming is traditional, innovative approaches have been developed to enhance its effectiveness and adaptability to different highland environments. Some of these innovative features include:

(1) **Contour strip cropping:** Alternating strips of different crops along the contour lines create a barrier against erosion and improves soil fertility.
(2) **Contour buffer strips:** Planting strips of perennial grasses or shrubs along the contour lines to filter runoff water, trap sediment, and provide habitat for beneficial insects.
(3) **Keyline design integration:** Combining contour farming with Keyline design principles to optimize water management and soil conservation across the landscape.
(4) **Precision contouring:** Utilizing GPS technology and precision farming tools to create accurate contour lines and optimize planting patterns.

4.4.3 Contribution to Productivity Improvement

Contour farming can contribute to productivity improvement in highlands in several ways:

(1) **Reduced soil erosion:** Contour farming significantly reduces soil erosion by slowing down water flow and trapping sediment, thereby conserving topsoil and nutrients.

(2) **Improved water infiltration:** By creating furrows and ridges along the contour lines, contour farming increases water infiltration into the soil, making more water available for plant growth.
(3) **Enhanced soil moisture retention:** Contour farming helps to retain soil moisture by reducing runoff and promoting infiltration, leading to improved crop yields, especially during dry periods.
(4) **Increased nutrient availability:** By reducing soil erosion and promoting organic matter accumulation, contour farming can enhance soil fertility and nutrient availability for plants.

4.4.4 Contribution to Climate Resilience

Contour farming can enhance climate resilience in highlands by:

(1) **Protecting against soil erosion:** Contour farming helps to protect against soil erosion caused by heavy rainfall and extreme weather events, which are becoming more frequent and intense due to climate change.
(2) **Conserving water resources:** Contour farming improves water infiltration and retention, conserving water resources and making crops more resilient to drought.
(3) **Mitigating landslide risk:** Contour farming can help to stabilize slopes and reduce the risk of landslides, which can be triggered by heavy rainfall and earthquakes.
(4) **Enhancing soil health:** By improving soil structure, organic matter content, and nutrient cycling, contour farming can enhance soil health and resilience to climate stressors.

4.4.5 Contribution to Greenhouse Gas Mitigation

Contour farming can contribute to greenhouse gas mitigation by:

(1) **Increasing soil carbon sequestration:** Contour farming can improve soil organic matter content, increase soil carbon sequestration, and reduce carbon dioxide emissions.
(2) **Reducing emissions from soil erosion:** Contour farming can reduce soil erosion, releasing carbon dioxide and other greenhouse gases into the atmosphere.
(3) **Minimizing soil disturbance:** Contour farming can reduce the need for tillage, which can release carbon dioxide from the soil.

4.4.6 Social Impact

Contour farming can have positive social impacts in highlands by:

(1) **Improving livelihoods:** Contour farming can increase agricultural productivity and income, leading to improved livelihoods for farmers and their families.
(2) **Enhancing food security:** Contour farming can contribute to food security by increasing crop yields and reducing the risk of crop failure due to soil erosion and water scarcity.
(3) **Promoting community participation:** Contour farming projects can involve community participation in planning, implementation, and maintenance, fostering social cohesion and empowerment.

4.4.7 Economic Impact

Contour farming can have positive economic impacts in highlands by:

(1) **Increasing agricultural productivity:** Contour farming can lead to increased crop yields and higher incomes for farmers.
(2) **Reducing input costs:** By improving water management and soil fertility, contour farming can reduce the need for irrigation, fertilizers, and pesticides, lowering input costs for farmers.

(3) **Creating employment opportunities:** Contour farming projects can generate employment opportunities in planning, implementing, and maintaining contour systems.

4.4.8 Other Ecosystem Benefits

Contour farming can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved biodiversity:** Contour farming can create diverse microhabitats that support a variety of plant and animal species.
(2) **Enhanced water quality:** By reducing erosion and improving water infiltration, contour farming can enhance water quality in rivers and streams.
(3) **Increased groundwater recharge:** Contour farming can help to recharge groundwater aquifers, ensuring long-term water availability.

4.4.9 Disadvantages and Tradeoffs, if any

Contour farming may have some disadvantages and tradeoffs, including:

(1) **Initial investment costs:** Implementing contour farming may require initial investment in surveying, land preparation, and equipment.
(2) **Technical expertise:** Designing and implementing contour farming systems may require technical expertise and knowledge of land surveying and soil conservation practices.
(3) **Maintenance requirements:** Contour farming systems require ongoing maintenance to ensure their effectiveness and prevent erosion.

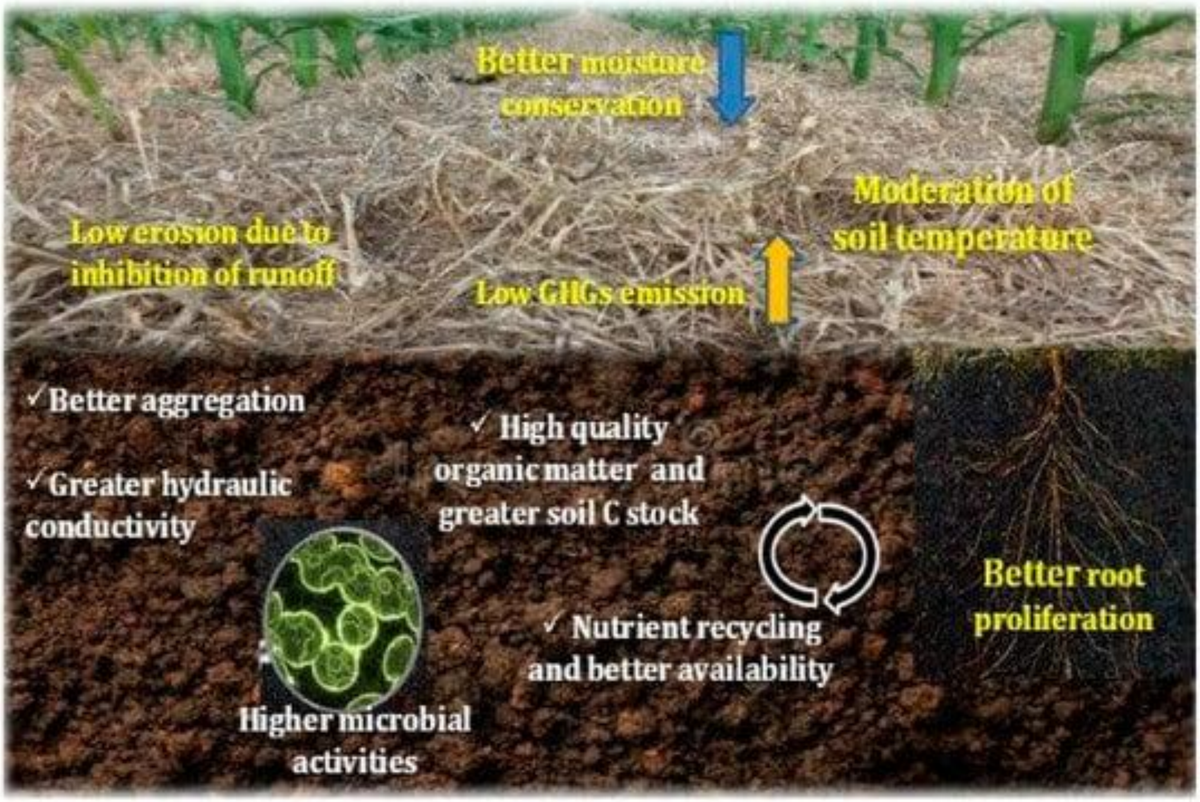
4.4.10 Other Information

Contour farming is a well-established and effective CSA practice that can be adapted to various highland environments and farming systems. It can be implemented on a small scale by individual farmers or on a larger scale through community-based projects. The success of contour farming depends on careful planning, appropriate design, and ongoing maintenance.

4.5 Traditional Organic Composting

4.5.1 Background

Traditional organic composting is a natural process of decomposing organic matter into a nutrient-rich soil amendment, such as crop residues, animal manure, and food waste. This practice has been used for centuries in various agricultural systems and is recognized for its benefits in improving soil fertility, enhancing crop yields, and promoting sustainable agriculture. In the context of climate change, traditional organic composting is considered a climate-smart agricultural (CSA) practice due to its potential to sequester carbon, reduce greenhouse gas emissions, and improve soil resilience to climate stressors.



Source: https://www.mdpi.com/2071-1050/12/23/9808

4.5.2 Innovative Features

While traditional organic composting is an age-old practice, innovative approaches have been developed to optimize the composting process and enhance its benefits. Some of these innovative features include:

(1) **Aerated static pile composting:** This method involves creating piles of organic matter with air channels to ensure adequate oxygen supply for efficient decomposition.
(2) **Vermicomposting:** This method utilizes earthworms to accelerate decomposition and produce nutrient-rich vermicompost.
(3) **Bokashi composting:** This method involves fermenting organic matter with a special inoculant to produce a pre-compost that can be quickly incorporated into the soil.
(4) **Biochar integration:** Adding biochar to compost can enhance its carbon sequestration potential and improve its nutrient retention capacity.

4.5.3 Contribution to Productivity Improvement

Traditional organic composting can contribute to productivity improvement in highlands in several ways:

(1) **Enhanced soil fertility:** Compost adds organic matter and essential nutrients to the soil, improving its fertility and promoting healthy plant growth.
(2) **Improved soil structure:** Compost can enhance soil structure, increasing its water-holding capacity, aeration, and drainage, which are crucial for crop productivity in highlands.
(3) **Increased microbial activity:** Compost introduces beneficial microorganisms into the soil, which can help to break down organic matter, release nutrients, and suppress plant diseases.

4.5.4 Contribution to Climate Resilience

Traditional organic composting can enhance climate resilience in highlands by:

(1) **Improving soil water retention:** Compost can increase the soil's water-holding capacity, making crops more resilient to drought and reducing the need for irrigation.
(2) **Protecting against soil erosion:** Compost can improve soil structure and aggregation, reducing the risk of soil erosion caused by heavy rainfall and extreme weather events.
(3) **Enhancing nutrient cycling:** Compost can promote efficient nutrient cycling in the soil, making nutrients more available to plants and reducing the need for synthetic fertilizers.

4.5.5 Contribution to Greenhouse Gas Mitigation

Traditional organic composting can contribute to greenhouse gas mitigation by:

(1) **Sequestering carbon:** Compost can sequester carbon in the soil, removing carbon dioxide from the atmosphere and storing it in a stable form.
(2) **Reducing methane emissions:** Composting organic matter under controlled conditions can reduce methane emissions compared to anaerobic decomposition in landfills.
(3) **Decreasing nitrous oxide emissions:** Compost can improve nitrogen use efficiency in the soil, reducing the risk of nitrous oxide emissions from excess nitrogen fertilizer application.

4.5.6 Social Impact

Traditional organic composting can have positive social impacts in highlands by:

(1) **Promoting sustainable agriculture:** Composting can reduce the reliance on synthetic fertilizers and pesticides, promoting sustainable agricultural practices.
(2) **Improving livelihoods:** Compost can enhance crop yields and income, leading to improved livelihoods for farmers and their families.
(3) **Enhancing food security:** Compost can contribute to food security by increasing crop yields and improving soil health.

4.5.7 Economic Impact

Traditional organic composting can have positive economic impacts in highlands by:

(1) **Reducing input costs:** Compost can lessen the need for expensive synthetic fertilizers and pesticides, lowering input costs for farmers.
(2) **Increasing crop yields:** Compost can improve soil fertility and crop yields, leading to higher incomes for farmers.
(3) **Creating market opportunities:** Compost can be sold as a valuable soil amendment, creating additional income sources for farmers and entrepreneurs.

4.5.8 Other Ecosystem Benefits

Traditional organic composting can provide a range of other ecosystem benefits in highlands, including:

(1) **Waste reduction:** Composting can divert organic waste from landfills, reducing the environmental impact of waste disposal.
(2) **Improved soil biodiversity:** Compost can enhance soil biodiversity by introducing beneficial microorganisms and promoting a healthy soil ecosystem.
(3) **Reduced water pollution:** Compost can improve soil nutrient retention, reducing the risk of nutrient runoff and water pollution.

4.5.9 Disadvantages and Tradeoffs, if any

Traditional organic composting may have some disadvantages and tradeoffs, including:

(1) **Labor-intensive:** Composting can be labor-intensive, requiring time and effort to collect, sort, and manage organic materials.
(2) **Space requirements:** Composting requires space for composting piles or bins, which may be limited in some highland areas.
(3) **Potential for odor and pests:** Improperly managed compost piles can generate odors and attract pests, which can be a nuisance for neighboring communities.

4.5.10 Other Information

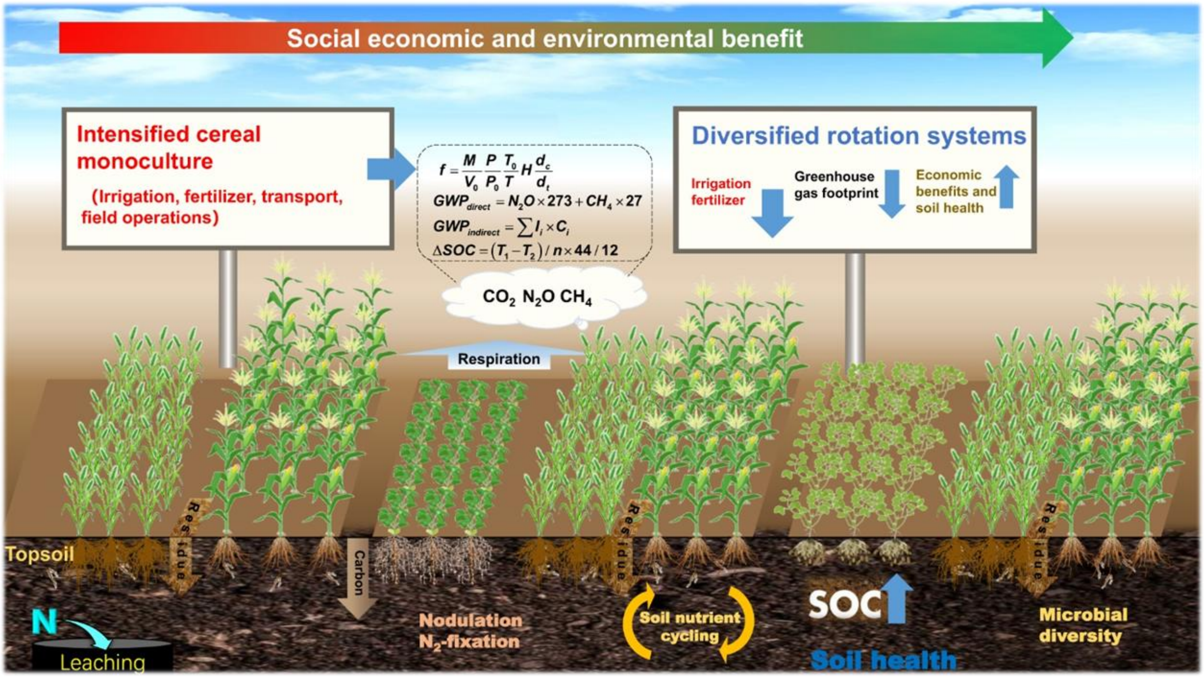
Traditional organic composting is a valuable CSA practice that can be quickly adopted by farmers in highlands. It can be implemented on a small scale by individual households or on a larger scale by community groups or cooperatives. Composting success depends on proper management practices, including maintaining the correct moisture content, carbon-to-nitrogen ratio, and aeration.

5. Climate-Smart Crop Management

5.1 Crop Rotation

5.1.1 Background

Crop rotation is the practice of growing various crops in the same area in sequential seasons. It is a well-established agricultural technique that offers numerous benefits for soil health, pest and disease management, and overall farm sustainability. In the context of climate change, crop rotation is considered a climate-smart agricultural (CSA) practice due to its potential to improve soil fertility, enhance nutrient cycling, and reduce reliance on synthetic fertilizers and pesticides. These benefits are significant in highland regions, where soils are often fragile, vulnerable to erosion, and exposed to harsh climatic conditions.



Source: https://images.app.goo.gl/ksjgLy24X3TWypmP9

5.1.2 Innovative Features

Traditional crop rotation practices have evolved to incorporate innovative features that enhance their effectiveness and adaptability to different highland environments. Some of these innovative features include:

(1) **Cover cropping:** Integrating cover crops into the rotation improves soil fertility, suppresses weeds, and reduces erosion.
(2) **Intercropping:** Growing two or more crops together in the same field to maximize land use efficiency, improve nutrient cycling, and reduce pest and disease pressure.
(3) **Relay cropping:** Planting a second crop before the first crop is harvested to extend the growing season and maximize land productivity.
(4) **Crop diversification:** Diversifying crop rotations to include a broader range of crops with different nutrient requirements and pest and disease susceptibilities.

5.1.3 Contribution to Productivity Improvement

Crop rotation can contribute to productivity improvement in highlands in several ways:

(1) **Improved soil fertility:** Crop rotation can enhance soil fertility by alternating crops with different nutrient requirements, promoting nutrient cycling, and reducing nutrient depletion.
(2) **Reduced pest and disease pressure:** Crop rotation can disrupt the life cycles of pests and diseases, reducing their populations and minimizing crop losses.
(3) **Enhanced soil structure:** Crop rotation can improve soil structure by incorporating crops with different root systems, breaking up compaction and enhancing aeration and drainage.
(4) **Increased biodiversity:** Crop rotation can increase biodiversity in the field, which can enhance ecosystem services, such as pollination and pest control.

5.1.4 Contribution to Climate Resilience

Crop rotation can enhance climate resilience in highlands by:

(1) **Improving soil health:** Crop rotation can improve soil health by increasing organic matter content, nutrient cycling, and microbial activity, making soils more resilient to climate stressors.
(2) **Reducing soil erosion:** Crop rotation can reduce soil erosion by incorporating cover crops and crops with extensive root systems, which help to bind the soil and prevent erosion.
(3) **Enhancing water use efficiency:** Crop rotation can improve water use efficiency by alternating crops with different water requirements and incorporating drought-tolerant crops.
(4) **Mitigating the impact of extreme weather events:** Crop rotation can help reduce the effects of extreme weather events, such as floods or droughts, by diversifying crop production and reducing reliance on a single crop.

5.1.5 Contribution to Greenhouse Gas Mitigation

Crop rotation can contribute to greenhouse gas mitigation by:

(1) **Increasing soil carbon sequestration:** Crop rotation can increase soil organic matter content, sequester carbon, and reduce carbon dioxide emissions.
(2) **Reducing nitrous oxide emissions:** Crop rotation can improve nitrogen use efficiency in the soil, reducing the risk of nitrous oxide emissions from excess nitrogen fertilizer application.
(3) **Minimizing soil disturbance:** Crop rotation can reduce the need for tillage, which can release carbon dioxide from the soil.

5.1.6 Social Impact

Crop rotation can have positive social impacts in highlands by:

(1) **Improving livelihoods:** Crop rotation can increase agricultural productivity and income, leading to improved livelihoods for farmers and their families.
(2) **Enhancing food security:** Crop rotation can contribute to food security by diversifying crop production and reducing the risk of crop failure due to pests, diseases, or extreme weather events.
(3) **Promoting sustainable agriculture:** Crop rotation can reduce the reliance on synthetic fertilizers and pesticides, promoting sustainable agricultural practices.

5.1.7 Economic Impact

Crop rotation can have positive economic impacts in highlands by:

(1) **Increasing crop yields:** Crop rotation can improve soil fertility and crop yields, leading to higher incomes for farmers.
(2) **Reducing input costs:** Crop rotation can reduce the need for fertilizers and pesticides, lowering input costs for farmers.
(3) **Diversifying income sources:** Crop rotation can diversify income sources by allowing farmers to grow various crops with different market values.

5.1.8 Other Ecosystem Benefits

Crop rotation can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved soil biodiversity:** Crop rotation can enhance soil biodiversity by supporting a wider range of soil organisms.
(2) **Reduced water pollution:** Crop rotation can reduce nutrient runoff and soil erosion, improving water quality in rivers and streams.
(3) **Enhanced wildlife habitat:** Crop rotation can provide habitat and food sources for beneficial insects and other wildlife.

5.1.9 Disadvantages and Tradeoffs, if any

Crop rotation may have some disadvantages and tradeoffs, including:

(1) **Increased management complexity:** Crop rotation requires careful planning and management to ensure that suitable crops are grown in the right sequence.
(2) **Potential for yield variability:** Crop yields may vary from year to year depending on the specific crops grown and the prevailing weather conditions.
(3) **Market limitations:** In some cases, market demand for specific crops may be limited, making it difficult for farmers to sell their produce.

5.1.10 Other Information

Crop rotation is a versatile and adaptable CSA practice that can be tailored to different highland regions' specific needs and conditions. It can be implemented on a small scale by individual farmers or on a larger scale through community-based projects. The success of crop rotation depends on careful planning, appropriate crop selection, and effective management practices.

5.2 Cover Cropping

5.2.1 Background

Cover cropping is the practice of planting specific crops, primarily to manage soil erosion, soil fertility, soil quality, water, weeds, pests, diseases, biodiversity, and wildlife in an agroecosystem. Cover crops are typically grown during fallow periods or between cash crop cycles. In the context of climate change, cover cropping is gaining recognition as a climate-smart agricultural (CSA) practice due to its multiple benefits, including soil conservation, improved nutrient cycling, and enhanced carbon sequestration. These benefits are significant in highland regions, where soil is often susceptible to erosion, nutrient depletion, and water stress.

Source: https://images.app.goo.gl/NitsHbiJpRBhpoXq6

5.2.2 Innovative Features

Traditional cover cropping practices have evolved to incorporate innovative features that enhance their effectiveness and adaptability to different highland environments. Some of these innovative features include:

(1) **Multi-species cover crop mixes:** Planting a diverse mix of cover crop species to maximize benefits, such as nitrogen fixation, weed suppression, and soil structure improvement.
(2) **Living mulches:** Using cover crops as living mulches to suppress weeds, conserve soil moisture, and add organic matter to the soil.
(3) **Green manure:** Incorporating cover crops into the soil as green manure to improve soil fertility and nutrient cycling.
(4) **Roller-crimping:** Terminating cover crops by rolling and crimping them, creating a mulch layer that suppresses weeds and conserves soil moisture.

5.2.3 Contribution to Productivity Improvement

Cover cropping can contribute to productivity improvement in highlands in several ways:

(1) **Improved soil fertility:** Cover crops, especially legumes, can fix atmospheric nitrogen and add organic matter to the soil, improving its fertility and promoting healthy plant growth.

(2) **Enhanced nutrient cycling:** Cover crops can scavenge nutrients from deep soil layers and release them back to the surface, making them available for subsequent crops.
(3) **Reduced soil erosion:** Cover crops protect the soil surface from the erosive forces of wind and water, conserving topsoil and nutrients.
(4) **Improved soil structure:** Cover crops can improve soil structure by increasing organic matter content, promoting aggregation, and enhancing water infiltration and drainage.

5.2.4 Contribution to Climate Resilience

Cover cropping can enhance climate resilience in highlands by:

(1) **Protecting against soil erosion:** Cover crops help to protect against soil erosion caused by heavy rainfall and extreme weather events, which are becoming more frequent and intense due to climate change.
(2) **Conserving soil moisture:** Cover crops can reduce evaporation from the soil surface, conserving moisture and making it available for plant growth during dry periods.
(3) **Moderating soil temperature:** Cover crops can moderate soil temperature, protecting plant roots from extreme heat or cold and creating a more favourable environment for growth.
(4) **Improving soil health:** Cover crops can enhance soil health by increasing organic matter content, promoting microbial activity, and suppressing soilborne pests and diseases.

5.2.5 Contribution to Greenhouse Gas Mitigation

Cover cropping can contribute to greenhouse gas mitigation by:

(1) **Increasing soil carbon sequestration:** Cover crops can increase soil organic matter content, which can sequester carbon and reduce carbon dioxide emissions.
(2) **Reducing nitrous oxide emissions:** Cover crops can improve nitrogen use efficiency in the soil, reducing the risk of nitrous oxide emissions from excess nitrogen fertilizer application.
(3) **Minimizing soil disturbance:** Cover cropping can reduce the need for tillage, which can release carbon dioxide from the soil.

5.2.6 Social Impact

Cover cropping can have positive social impacts in highlands by:

(1) **Improving livelihoods:** Cover cropping can enhance soil fertility and crop yields, leading to increased income and improved livelihoods for farmers and their families.
(2) **Enhancing food security:** Cover cropping can contribute to food security by improving soil health, increasing crop yields, and reducing the risk of crop failure due to soil erosion and nutrient depletion.
(3) **Promoting sustainable agriculture:** Cover cropping can reduce the reliance on synthetic fertilizers and pesticides, promoting sustainable agricultural practices and protecting the environment.

5.2.7 Economic Impact

Cover cropping can have positive economic impacts in highlands by:

(1) **Reducing input costs:** Cover cropping can lessen the need for fertilizers and pesticides, lowering input costs for farmers.
(2) **Increasing crop yields:** Cover cropping can improve soil fertility and crop yields, leading to higher incomes for farmers.

(3) **Improving soil health:** Cover cropping can improve soil health, reducing long-term production costs associated with soil degradation and erosion.

5.2.8 Other Ecosystem Benefits

Cover cropping can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved biodiversity:** Cover crops can enhance biodiversity by providing habitat and food sources for beneficial insects, pollinators, and other wildlife.
(2) **Reduced water pollution:** Cover crops can reduce nutrient runoff and soil erosion, improving water quality in rivers and streams.
(3) **Enhanced soil health:** Cover crops can improve soil structure, water-holding capacity, and nutrient cycling, leading to healthier and more productive soils.

5.2.9 Disadvantages and Tradeoffs, if any

Cover cropping may have some disadvantages and tradeoffs, including:

(1) **Seed costs:** The initial cost of covering crop seeds can be a barrier for some farmers. However, cost-effective options, such as using locally adapted varieties or saving seeds from previous crops, are available.
(2) **Management requirements:** Cover crops require proper management, including timely planting, termination, and incorporation into the soil, to maximize their benefits and avoid potential drawbacks.
(3) **Potential for competition with cash crops:** In some cases, cover crops may compete with cash crops for water and nutrients, especially if not managed properly.

5.2.10 Other Information

Cover cropping is a versatile and adaptable CSA practice that can be tailored to different highland regions' specific needs and conditions. It can be integrated into various farming systems, including smallholder farms, commercial farms, and agroforestry systems. The success of cover cropping depends on careful planning, appropriate species selection, and effective management practices.

5.3 Conservation Agriculture

5.3.1 Background

Conservation Agriculture (CA) is a farming system that promotes minimum soil disturbance (no-till), maintenance of permanent soil cover (mulching), and diversification of plant species (crop rotation/intercropping). It is gaining prominence as a climate-smart agricultural (CSA) practice because it can improve soil health, enhance resource use efficiency, and mitigate climate change impacts. CA is particularly relevant in highland regions, where fragile soils are prone to erosion, water scarcity is a concern, and climate change exacerbates these challenges.

Source: https://images.app.goo.gl/XPGpy1P9FbduKCLV8

5.3.2 Innovative Features

CA is not a new concept, but its implementation has evolved with innovative approaches to suit diverse highland agroecosystems. Some of these innovative features include:

(1) **Precision no-till planters:** Utilizing specialized planters that can sow seeds directly into undisturbed soil, minimizing soil disturbance and preserving soil structure.

(2) **Cover crop cocktails:** Designing diverse cover crop mixes that address specific soil health needs, such as nitrogen fixation, weed suppression, or pest and disease control.
(3) **Integrated pest and nutrient management:** Incorporating integrated pest management (IPM) and nutrient management strategies to minimize the use of agrochemicals and promote ecological balance.
(4) **Contour farming and terracing:** Integrating CA principles with contour farming and terracing to further enhance soil and water conservation on sloping lands.

5.3.3 Contribution to Productivity Improvement

CA can contribute to productivity improvement in highlands in several ways:

(1) **Improved soil health:** CA practices enhance soil organic matter, structure, and biological activity, increasing soil fertility and crop nutrient availability.
(2) **Enhanced water use efficiency:** By minimizing soil disturbance and maintaining permanent soil cover, CA reduces water evaporation, improves infiltration, and enhances soil moisture retention.
(3) **Reduced input costs:** CA minimizes the need for tillage, which lowers fuel consumption and labor costs. Additionally, improved soil fertility and pest and disease suppression can reduce reliance on fertilizers and pesticides.
(4) **Increased yields over time:** While initial yields may be lower, CA systems often lead to increased and more stable yields over time due to improved soil health and resilience.

5.3.4 Contribution to Climate Resilience

CA can enhance climate resilience in highlands by:

(1) **Protecting against soil erosion:** The permanent soil cover and reduced tillage in CA systems protect the soil from erosion caused by heavy rainfall and wind, which are common in highland areas.
(2) **Conserving water resources:** CA practices improve water infiltration and retention, making crops more resilient to drought and reducing the need for irrigation.
(3) **Moderating soil temperature:** The soil cover in CA systems helps regulate soil temperature, protect plant roots from extreme heat or cold, and reduce stress.
(4) **Enhancing soil organic matter:** CA practices promote the accumulation of soil organic matter, which improves soil structure, water-holding capacity, and nutrient retention, making soils more resilient to climate stressors.

5.3.5 Contribution to Greenhouse Gas Mitigation

CA can contribute to greenhouse gas mitigation by:

(1) **Increasing soil carbon sequestration:** CA practices, such as reduced tillage and cover cropping, increase soil organic matter content, which sequesters carbon and reduces carbon dioxide emissions.
(2) **Reducing nitrous oxide emissions:** Improved nitrogen use efficiency in CA systems can reduce nitrous oxide emissions from agricultural soils.
(3) **Minimizing fuel consumption:** Reduced tillage in CA systems lowers fuel consumption and associated greenhouse gas emissions.

5.3.6 Social Impact

CA can have positive social impacts in the highlands by:

(1) **Improving livelihoods:** CA can increase agricultural productivity and profitability, leading to improved livelihoods for farmers and their families.

(2) **Enhancing food security:** CA can contribute to food security by improving soil health, increasing crop yields, and reducing the risk of crop failure due to soil erosion and water scarcity.
(3) **Promoting sustainable agriculture:** CA practices are environmentally friendly and promote the long-term sustainability of agricultural systems.

5.3.7 Economic Impact

CA can have positive economic impacts in the highlands by:

(1) **Reducing input costs:** CA minimizes the need for tillage, fertilizers, and pesticides, lowering input costs for farmers.
(2) **Increasing yields over time:** While initial yields may be lower, CA systems often lead to increased and more stable yields over time due to improved soil health and resilience.
(3) **Improving soil health:** CA practices enhance soil health, reducing long-term production costs associated with soil degradation and erosion.

5.3.8 Other Ecosystem Benefits

CA can provide a range of other ecosystem benefits in the highlands, including:

(1) **Improved biodiversity:** CA systems can support a greater diversity of soil organisms, beneficial insects, and other wildlife than conventional farming systems.
(2) **Reduced water pollution:** CA practices minimize soil erosion and nutrient runoff, improving water quality in rivers and streams.
(3) **Enhanced soil resilience:** CA practices improve soil structure, water-holding capacity, and nutrient retention, making soils more resilient to climate stressors and extreme weather events.

5.3.9 Disadvantages and Tradeoffs, if any

CA may have some disadvantages and tradeoffs, including:

(1) **Transition challenges:** Shifting from conventional farming to CA may require a learning curve and adjustments in management practices.
(2) **Weed management:** CA systems may require alternative weed management strategies, such as cover crops or herbicides, as tillage is minimized.
(3) **Pest and disease management:** CA systems may require integrated pest management (IPM) strategies to address potential pest and disease outbreaks.

5.3.10 Other Information

CA is a knowledge-intensive farming system that requires a holistic understanding of soil-plant-water interactions. Farmers adopting CA need access to training, technical support, and appropriate equipment to implement and manage CA practices successfully.

5.4 Crop Diversification

5.4.1 Background

Crop diversification is the practice of growing various crops on a farm or in a region rather than relying on a single crop or a limited number of crops. This practice has been traditionally used to reduce risks associated with pests, diseases, and market fluctuations. In the context of climate change, crop diversification is gaining recognition as a climate-smart agricultural (CSA) practice due to its potential to enhance resilience to climate variability, improve soil health, and provide multiple income streams for farmers. This practice is particularly relevant in highland regions, where diverse agroecological zones and microclimates offer opportunities for cultivating various crops.

Source: https://images.app.goo.gl/n6GvAZMpq1kWNxYD8

5.4.2 Innovative Features

Crop diversification can be implemented innovatively to maximize its benefits in highland agriculture. Some of these innovative features include:

(1) **Intercropping:** Growing two or more crops simultaneously in the same field, such as maize and beans, to optimize land use, improve nutrient cycling, and reduce pests and disease pressure.
(2) **Agroforestry:** Integrating trees and shrubs into crop fields to provide shade, windbreaks, and additional income sources while also improving soil fertility and biodiversity.
(3) **Crop rotations:** Alternating different crops in a planned sequence to break pest and disease cycles, improve soil health, and optimize nutrient utilization.
(4) **Integrating livestock:** Combining crop production with livestock rearing to create a more diversified and resilient farming system.
(5) **Value addition and processing:** Developing value-added products from diversified crops to increase their market value and provide additional income streams for farmers.

5.4.3 Contribution to Productivity Improvement

Crop diversification can contribute to productivity improvement in highlands in several ways:

(1) **Improved soil health:** Diversifying crops can enhance soil health by promoting nutrient cycling, increasing organic matter content, and reducing soil erosion.
(2) **Reduced pest and disease pressure:** Growing various crops can disrupt the life cycles of pests and diseases, reducing their populations and minimizing crop losses.
(3) **Enhanced resource use efficiency:** Different crops have varying nutrient and water requirements, and diversifying crops can optimize the use of these resources.
(4) **Increased pollination:** A diverse range of crops can attract a wider variety of pollinators, leading to improved pollination and higher yields.

5.4.4 Contribution to Climate Resilience

Crop diversification can enhance climate resilience in highlands by:

(1) **Reducing vulnerability to climate risks:** By growing various crops, farmers can reduce their reliance on a single crop and spread the risk of crop failure due to drought, floods, or other extreme weather events.
(2) **Improving soil health:** Diversifying crops can improve soil health, making it more resilient to climate stressors such as drought and erosion.
(3) **Enhancing water use efficiency:** Crop diversification can improve water use efficiency by incorporating drought-tolerant crops and optimizing irrigation practices.
(4) **Promoting agrobiodiversity:** A diverse range of crops can enhance agrobiodiversity, contributing to ecosystem resilience and adaptability to changing climatic conditions.

5.4.5 Contribution to Greenhouse Gas Mitigation

Crop diversification can contribute to greenhouse gas mitigation by:

(1) **Increasing soil carbon sequestration:** Diversifying crops, especially those with deep root systems can increase soil organic matter content, leading to increased carbon sequestration and reduced carbon dioxide emissions.
(2) **Reducing nitrous oxide emissions:** Crop diversification can improve nitrogen use efficiency in the soil, reducing the risk of nitrous oxide emissions from excess nitrogen fertilizer application.
(3) **Minimizing pesticide use:** Diversifying crops can reduce the need for pesticides by disrupting pest and disease cycles, leading to lower greenhouse gas emissions associated with pesticide production and use.

5.4.6 Social Impact

Crop diversification can have positive social impacts in highlands by:

(1) **Improving livelihoods:** Crop diversification can provide farmers with multiple income streams, reducing their vulnerability to market fluctuations and enhancing their livelihoods.
(2) **Enhancing food security:** Diversifying crops can improve dietary diversity and nutritional security for farming households and communities.
(3) **Empowering women:** Crop diversification can allow women to participate in decision-making and income generation, empowering them within their households and communities.

5.4.7 Economic Impact

Crop diversification can have positive economic impacts in highlands by:

(1) **Increasing income stability:** Diversifying crops can provide farmers with multiple income streams, reducing their dependence on a single crop and providing a buffer against market fluctuations.
(2) **Enhancing market opportunities:** Diversified crops can create new market opportunities for farmers, especially for high-value crops or niche products.

(3) **Promoting rural development:** Crop diversification can stimulate local economies by creating demand for agricultural inputs, processing, and marketing services.

5.4.8 Other Ecosystem Benefits

Crop diversification can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved soil health:** Diversifying crops can enhance soil health by promoting nutrient cycling, increasing organic matter content, and reducing soil erosion.
(2) **Enhanced biodiversity:** A diverse range of crops can support a wider variety of pollinators, beneficial insects, and other wildlife, contributing to ecosystem health and resilience.
(3) **Reduced water pollution:** Crop diversification can reduce nutrient and pesticide runoff from agricultural fields, improving water quality in rivers and streams.

5.4.9 Disadvantages and Tradeoffs, if any

Crop diversification may have some disadvantages and tradeoffs, including:

(1) **Increased management complexity:** Managing a diverse range of crops can be more complex than managing a single crop, requiring additional knowledge and skills.
(2) **Market challenges:** Marketing a diverse range of crops can be challenging, especially for small-scale farmers who may lack access to markets and infrastructure.
(3) **Potential for yield variability:** Yields of different crops may vary depending on weather conditions, pest and disease pressure, and market demand.

5.4.10 Other Information

Crop diversification is a crucial strategy for promoting sustainable and resilient agriculture in the highlands. It can be implemented in various ways, depending on the specific context and resources available. Successful crop diversification requires careful planning, knowledge of local agroecological conditions, and access to markets and support services.

5.5 Growing Drought-Tolerant Crops

5.5.1 Background

Drought is a major challenge for agriculture, particularly in highland regions where water resources are often limited, and rainfall patterns are becoming increasingly unpredictable due to climate change. Growing drought-tolerant crops is a climate-smart agricultural (CSA) practice that can help farmers adapt to water scarcity and ensure food security. Drought-tolerant crops are varieties that have been bred or selected for their ability to withstand prolonged periods of low rainfall and high temperatures. These crops can maintain yield and quality even under water-stressed conditions, making them a valuable tool for farmers in drought-prone areas.

Source: https://images.app.goo.gl/Aq3K9aNSDpfj7sXr6

5.5.2 Innovative Features

Traditional drought-tolerant crops have been cultivated for centuries, but recent advances in plant breeding and biotechnology have led to the development of new and improved varieties with enhanced drought tolerance and yield potential. Some of the innovative features of drought-tolerant crops include:

(1) **Genetic engineering:** Introducing genes from other plant species or microorganisms that confer drought tolerance traits, such as improved water-use efficiency, enhanced root systems, or increased osmotic adjustment.
(2) **Marker-assisted selection:** Using molecular markers to identify and select drought tolerance traits in breeding programs, accelerating the development of new varieties.
(3) **Participatory plant breeding:** Involving farmers in selecting and evaluating drought-tolerant varieties to ensure that they are adapted to local conditions and meet farmers' needs.
(4) **Seed priming and coating:** Treating seeds with beneficial microbes or nutrients to improve germination and seedling establishment under drought conditions.

5.5.3 Contribution to Productivity Improvement

Growing drought-tolerant crops can contribute to productivity improvement in highlands in several ways:

(1) **Maintaining yields under drought conditions:** Drought-tolerant crops can maintain yields even under water-stressed conditions, ensuring farmers' stable food supply and income.
(2) **Reducing crop losses:** By withstanding drought, these crops can reduce crop losses due to water scarcity, which can be significant in highland areas.
(3) **Improving water use efficiency:** Drought-tolerant crops often have improved water-use efficiency, meaning they can produce more yield per unit of water consumed.
(4) **Expanding cropping options:** Drought-tolerant crops can broaden the range of crops that can be grown in water-limited environments, providing farmers with more options for diversification and income generation.

5.5.4 Contribution to Climate Resilience

Growing drought-tolerant crops can enhance climate resilience in highlands by:

(1) **Reducing vulnerability to drought:** Drought-tolerant crops are less vulnerable to drought, reducing the risk of crop failure and ensuring food security in the face of climate change.
(2) **Adapting to changing rainfall patterns:** Drought-tolerant crops can adapt to changing rainfall patterns by maintaining yields even during periods of low rainfall.
(3) **Conserving water resources:** By improving water-use efficiency, drought-tolerant crops can help to conserve water resources, which are becoming increasingly scarce in many highland regions.

5.5.5 Contribution to Greenhouse Gas Mitigation

Growing drought-tolerant crops can indirectly contribute to greenhouse gas mitigation by:

(1) **Reducing the need for irrigation:** Drought-tolerant crops require less irrigation, which can reduce energy consumption and associated greenhouse gas emissions from pumping water.
(2) **Minimizing fertilizer use:** Drought-tolerant crops often have improved nutrient-use efficiency, reducing the need for fertilizers and associated greenhouse gas emissions from fertilizer production and application.

5.5.6 Social Impact

Growing drought-tolerant crops can have positive social impacts in highlands by:

(1) **Improving livelihoods:** Drought-tolerant crops can increase income stability and reduce the risk of crop failure, leading to improved livelihoods for farmers and their families.
(2) **Enhancing food security:** Drought-tolerant crops can ensure a stable food supply even during droughts, contributing to food security in highland communities.
(3) **Empowering farmers:** This practice can enable farmers to adapt to climate change and improve their resilience by giving them access to drought-tolerant seeds and information.

5.5.7 Economic Impact

Growing drought-tolerant crops can have positive economic impacts in highlands by:

(1) **Increasing income stability:** Drought-tolerant crops can provide farmers with a more stable income by reducing the risk of crop failure due to drought.
(2) **Reducing input costs:** Drought-tolerant crops often require less irrigation and fertilizer, lowering input costs for farmers.
(3) **Improving market access:** Drought-tolerant crops can open new market opportunities for farmers, especially for high-value crops that can be grown in water-limited environments.

5.5.8 Other Ecosystem Benefits

Growing drought-tolerant crops can provide a range of other ecosystem benefits in highlands, including:

(1) **Conserving water resources:** Drought-tolerant crops can help to conserve water resources by reducing the demand for irrigation.
(2) **Protecting soil health:** Drought-tolerant crops can help to maintain soil health by reducing the risk of soil erosion and degradation caused by drought.
(3) **Promoting biodiversity:** Drought-tolerant crops can contribute to agrobiodiversity by providing alternative cropping options in water-limited environments.

5.5.9 Disadvantages and Tradeoffs, if any

Growing drought-tolerant crops may have some disadvantages and tradeoffs, including:

(1) **Limited availability of seeds:** Drought-tolerant seeds may not be readily available for all crops or in all regions.
(2) **Higher seed costs:** Drought-tolerant seeds may be more expensive than conventional seeds.
(3) **Potential yield penalties:** Some drought-tolerant varieties may have lower yield potential than conventional varieties under non-stress conditions.

5.5.10 Other Information

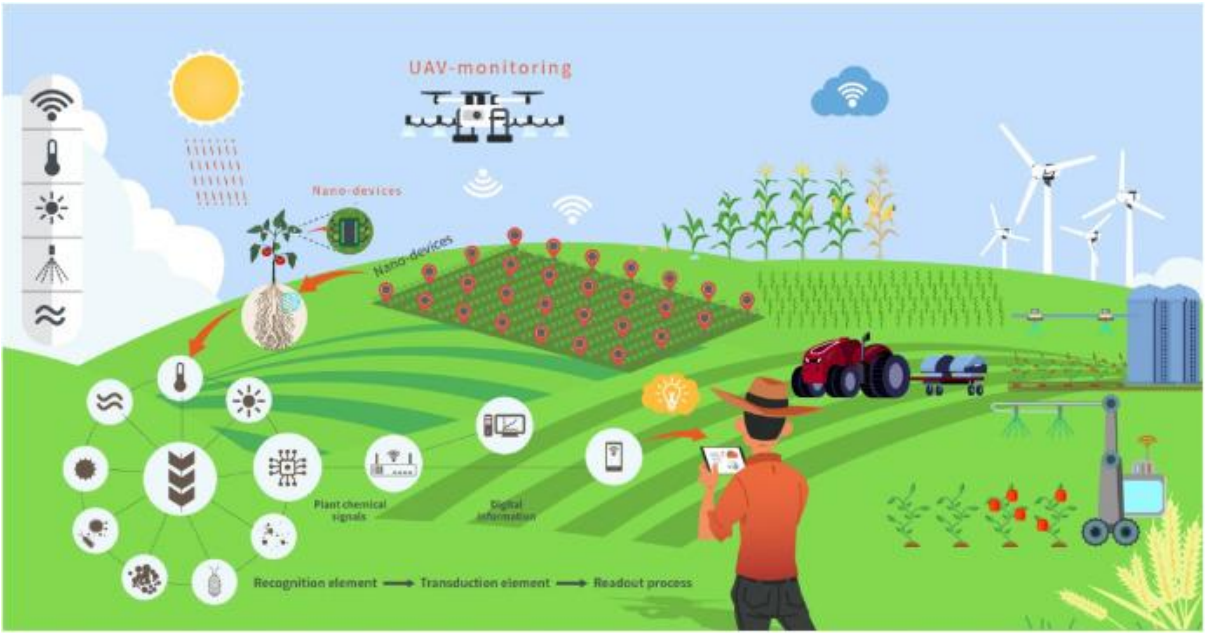
Growing drought-tolerant crops is a crucial CSA practice for adapting to climate change and ensuring food security in highland regions. It is vital to select drought-tolerant varieties that are well-suited to the region's specific climatic and soil conditions. Farmers should also consider integrating drought-tolerant crops with other CSA practices, such as water harvesting and conservation tillage, to maximize their benefits.

6. Digital Technology-Based Solutions

6.1 Precision Agriculture

6.1.1 Background

Precision agriculture (PA) refers to using information technology, satellite imagery, sensors, and other tools to optimize agricultural practices and resource management. By collecting and analyzing data on soil conditions, crop growth, and weather patterns, farmers can make informed decisions about irrigation, fertilization, and pest control, leading to increased efficiency, reduced input costs, and improved environmental sustainability. In the context of climate change, PA is emerging as a crucial climate-smart agricultural (CSA) practice due to its potential to enhance resource use efficiency, optimize crop production, and mitigate the impacts of climate variability.



Source: https://images.app.goo.gl/bCePBbxJjTFQrdY57

6.1.2 Innovative Features

PA is constantly evolving, with new technologies and approaches being developed to address the specific challenges of highland agriculture. Some of the innovative features of PA in the highlands include:

(1) **Remote sensing and satellite imagery:** Utilizing satellite imagery and drones to monitor crop health, identify stress areas, and assess soil moisture levels.

(2) **Soil sensors and mapping:** Deploying soil sensors to collect data on soil moisture, nutrient levels, and temperature and creating detailed soil maps to guide site-specific management decisions.

(3) **Variable rate technology:** Applying fertilizers, pesticides, and irrigation water at variable rates based on the specific needs of different areas within a field.

(4) **Crop modelling and decision support systems:** Utilizing crop growth models and decision support systems to predict crop yields, optimize planting dates, and manage pest and disease risks.

6.1.3 Contribution to Productivity Improvement

PA can contribute to productivity improvement in highlands in several ways:

(1) **Optimized resource use:** PA enables farmers to apply inputs, such as water, fertilizers, and pesticides, precisely where and when they are needed, minimizing waste and maximizing efficiency.
(2) **Improved crop management:** By monitoring crop health and identifying stress areas early on, farmers can take timely corrective actions to prevent yield losses.
(3) **Enhanced decision-making:** PA provides farmers with data-driven insights to make informed decisions about crop management, leading to improved yields and profitability.
(4) **Site-specific management:** PA allows farmers to tailor their management practices to the specific needs of different areas within a field, optimizing resource use and maximizing yields.

6.1.4 Contribution to Climate Resilience

PA can enhance climate resilience in highlands by:

(1) **Efficient water management:** PA can help farmers optimize irrigation schedules based on real-time soil moisture data, reducing water waste and improving drought resilience.
(2) **Early crop stress detection:** PA tools can detect early signs of crop stress due to heat, drought, or pests, allowing farmers to take timely action to mitigate damage.
(3) **Improved soil health:** PA practices, such as reduced tillage and targeted nutrient management, can improve soil health and resilience to climate stressors.
(4) **Data-driven decision-making:** PA provides farmers with the information they need to make informed decisions about crop management in the face of climate variability and extreme weather events.

6.1.5 Contribution to Greenhouse Gas Mitigation

PA can contribute to greenhouse gas mitigation by:

(1) **Reducing fertilizer use:** PA enables farmers to optimize fertilizer application rates, reducing nitrogen losses and associated nitrous oxide emissions.
(2) **Minimizing pesticide use:** PA tools can help farmers identify pest infestations early on, allowing for targeted pesticide applications and reducing overall pesticide use.
(3) **Optimizing irrigation:** PA can help farmers maximize irrigation schedules, reducing water pumping energy consumption and associated greenhouse gas emissions.

6.1.6 Social Impact

PA can have positive social impacts in highlands by:

(1) **Improving livelihoods:** PA can increase agricultural productivity and profitability, leading to improved livelihoods for farmers and their families.
(2) **Enhancing food security:** PA can contribute to food security by optimizing crop production and reducing the risk of crop failure due to climate stressors.
(3) **Empowering farmers:** PA provides farmers with access to information and tools that enable them to make informed decisions about their farming practices.

6.1.7 Economic Impact

PA can have positive economic impacts in the highlands by:

(1) **Reducing input costs:** PA can reduce the cost of fertilizers, pesticides, and irrigation water by optimizing their use.

(2) **Increasing yields:** PA can improve crop yields through optimized management practices, leading to higher incomes for farmers.
(3) **Improving profitability:** PA can enhance farm profitability by reducing costs and increasing yields.

6.1.8 Other Ecosystem Benefits

PA can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved soil health:** PA practices, such as reduced tillage and targeted nutrient management, can improve soil health and biodiversity.
(2) **Reduced water pollution:** PA can reduce nutrient and pesticide runoff from agricultural fields, improving water quality in rivers and streams.
(3) **Enhanced ecosystem services:** PA can enhance ecosystem services, such as pollination and pest control, by promoting biodiversity and ecological balance.

6.1.9 Disadvantages and Tradeoffs, if any

PA may have some disadvantages and tradeoffs, including:

(1) **High initial investment costs:** PA technologies can be expensive, especially for small-scale farmers. However, government subsidies and innovative financing models can help to overcome this barrier.
(2) **Technical expertise:** PA requires technical expertise and data analysis and interpretation knowledge, which may be a challenge for some farmers.
(3) **Data privacy concerns:** The collection and use of agricultural data raises concerns about data privacy and security.

6.1.10 Other Information

PA is a rapidly evolving field with new technologies and approaches emerging constantly. It has the potential to revolutionize agriculture in the highlands by enabling farmers to make data-driven decisions, optimize resource use, and adapt to the challenges of climate change. The success of PA depends on access to affordable technology, training and support for farmers, and collaboration among stakeholders.

6.2 Climate Information Services

6.2.1 Background

Climate Information Services (CIS) play a pivotal role in climate-smart agriculture (CSA) by empowering farmers with accurate and timely weather forecasts, seasonal outlooks, and other climate-related information. This knowledge enables them to make informed decisions about planting, harvesting, irrigation, and other agricultural activities, thereby minimizing risks and maximizing yields. In highland regions, where weather patterns are often unpredictable and extreme events are becoming more frequent, CIS is particularly crucial for building resilience and adapting to climate change.

6.2.2 Key Climate Information Services CSA Practices

(1) **Weather Forecasts and Early Warning Systems:** Providing farmers with accurate and localized weather forecasts, including short-term predictions and early warnings for extreme events like storms, floods, or droughts, is essential. This allows farmers to take proactive measures, such as adjusting planting schedules, protecting crops, or evacuating livestock to minimize potential damage.

(2) **Seasonal Climate Outlooks:** Seasonal forecasts provide information about expected temperature and rainfall patterns over the coming months. This helps farmers select suitable crop varieties, plan planting and harvesting dates, and make informed decisions about water management and irrigation strategies.

(3) **Climate Risk Assessments and Vulnerability Mapping:** Conducting climate risk assessments and developing vulnerability maps can help identify areas and communities that are most at risk from climate change impacts. This information can guide the development of targeted interventions and adaptation strategies.

(4) **Crop-Specific Advisories:** Providing farmers with crop-specific advisories based on weather forecasts and climate data can help them optimize their farming practices. This can include planting dates, irrigation schedules, fertilizer application, and pest and disease management recommendations.

(5) **Index-Based Insurance:** Index-based insurance products can financially protect farmers against weather-related risks. These insurance schemes are based on pre-defined weather indices, such as rainfall or temperature thresholds, and pay out automatically when these thresholds are exceeded, providing farmers with timely financial support to recover from losses.

(6) **Mobile Phone-Based Information Dissemination:** Utilizing mobile phone technology to disseminate climate information and advisories to farmers in remote areas can be highly effective. SMS alerts, voice messages, and mobile apps can provide farmers with real-time information and decision-support tools.

(7) **Participatory Approaches:** Engaging farmers in the design and delivery of CIS ensures that the information provided is relevant, understandable, and actionable. Participatory approaches can also help build trust and ownership among farmers, leading to increased uptake and utilization of climate information.

6.2.3 Benefits of Climate Information Services in Highlands

(1) **Improved Decision-Making:** CIS empowers farmers to make informed decisions about their agricultural activities, reducing uncertainty and minimizing risks associated with weather variability and extreme events.

(2) **Increased Productivity:** By optimizing planting dates, irrigation schedules, and other practices based on climate information, farmers can increase crop yields and livestock productivity.

(3) **Enhanced Resilience:** CIS helps farmers anticipate and prepare for climate risks, such as droughts or floods, enabling them to protect their crops and livelihoods proactively.

(4) **Reduced Losses:** Early warning systems and timely advisories can help farmers minimize losses due to extreme weather events or pest and disease outbreaks.
(5) **Improved Livelihoods:** By increasing productivity, reducing losses, and enhancing resilience, CIS can improve livelihoods and food security for highland communities.

6.2.4 Challenges and Considerations

(1) **Accessibility:** Ensuring that CIS is accessible to all farmers, including those in remote areas with limited access to technology, is a key challenge.
(2) **Accuracy and Reliability:** The accuracy and reliability of climate information are crucial for its effectiveness. Investing in high-quality weather stations, data collection, and forecasting models is essential.
(3) **Local Relevance:** Climate information needs to be tailored to the specific needs and contexts of different highland regions and farming systems. This requires collaboration between meteorologists, agronomists, and farmers to develop locally relevant and actionable advisories.
(4) **Capacity Building:** Building the capacity of farmers to understand and utilize climate information is essential. This includes training on interpreting weather forecasts, using decision-support tools, and implementing climate-smart practices.

By addressing these challenges and investing in developing and disseminating climate information services, we can empower highland farmers to adapt to climate change, improve their livelihoods, and ensure a more sustainable and resilient future for agriculture in these vulnerable regions.

7. Livestock Management

7.1 Livestock Integration

7.1.1 Background

Livestock integration in agricultural systems involves strategically incorporating animals, such as cattle, sheep, goats, or poultry, into crop farming practices. This integrated approach aims to optimize resource utilization, improve soil fertility, and enhance overall farm productivity. In the context of climate change, livestock integration is considered a climate-smart agricultural (CSA) practice due to its potential to improve nutrient cycling, enhance carbon sequestration, and increase the resilience of farming systems to climate stressors. This practice is particularly relevant in highland regions, where livestock are often an integral part of traditional farming systems and play a crucial role in livelihoods and food security.

Source: https://images.app.goo.gl/cUdnKqrXnTVaYi8M6

7.1.2 Innovative Features

Livestock integration in highlands can be implemented innovatively to maximize its benefits and minimize potential negative impacts. Some of these innovative features include:

(1) **Rotational grazing:** Moving livestock between different paddocks or pastures to allow for vegetation recovery, improve soil health, and reduce the risk of overgrazing.

(2) **Silvopasture:** Integrating trees and shrubs into grazing systems to provide shade, shelter, and fodder for livestock while also improving soil fertility and carbon sequestration.

(3) **Mixed farming systems:** Combining crop and livestock production on the same farm to optimize resource utilization, improve nutrient cycling, and diversify income sources.
(4) **Manure management:** Implementing effective manure management practices, such as composting or anaerobic digestion, to reduce greenhouse gas emissions and produce valuable organic fertilizer.
(5) **Precision livestock farming:** Utilizing technology, such as GPS tracking and sensors, to monitor animal health, optimize feeding, and improve overall livestock management.

7.1.3 Contribution to Productivity Improvement

Livestock integration can contribute to productivity improvement in highlands in several ways:

(1) **Improved soil fertility:** Livestock manure can be used as a natural fertilizer, adding organic matter and essential nutrients to the soil, improving its fertility and promoting healthy plant growth.
(2) **Enhanced nutrient cycling:** Livestock can help to cycle nutrients between pastures and croplands, improving nutrient availability for plants and reducing the need for synthetic fertilizers.
(3) **Increased crop yields:** Integrating livestock into cropping systems can improve crop yields through manure fertilization, pest control, and improved soil structure.
(4) **Diversified income sources:** Livestock integration can provide farmers with additional income sources from animal products, such as milk, meat, and wool, reducing their reliance on a single crop.

7.1.4 Contribution to Climate Resilience

Livestock integration can enhance climate resilience in highlands by:

(1) **Improving soil health:** Livestock grazing, and manure application can improve soil health by increasing organic matter content, promoting microbial activity, and enhancing soil structure. Healthy soils are more resilient to drought, erosion, and climate stressors.
(2) **Enhancing carbon sequestration:** Well-managed grazing systems can sequester carbon in the soil, helping to mitigate climate change.
(3) **Diversifying production systems:** Integrating livestock into farming systems can diversify production and income sources, reducing vulnerability to climate risks and market fluctuations.
(4) **Providing ecosystem services:** Livestock can provide valuable ecosystem services, such as pollination, pest control, and seed dispersal, contributing to overall ecosystem resilience.

7.1.5 Contribution to Greenhouse Gas Mitigation

Livestock integration can contribute to greenhouse gas mitigation by:

(1) **Improving manure management:** Implementing effective manure management practices, such as composting or anaerobic digestion, can reduce methane emissions from livestock manure.
(2) **Enhancing carbon sequestration:** Well-managed grazing systems can sequester carbon in the soil, offsetting greenhouse gas emissions from livestock.
(3) **Reducing reliance on synthetic fertilizers:** Livestock manure can be used as a natural fertilizer, reducing the need for synthetic fertilizers, which are a significant source of greenhouse gas emissions.

7.1.6 Social Impact

Livestock integration can have positive social impacts in highlands by:

(1) **Improving livelihoods:** Livestock integration can provide farmers with additional income sources and improve food security, enhancing their livelihoods and well-being.
(2) **Creating employment opportunities:** Livestock production can generate employment opportunities in animal husbandry, processing, and marketing, contributing to rural development.
(3) **Preserving cultural heritage:** Livestock is often an integral part of cultural traditions and practices in highland communities, and its integration into farming systems can help preserve this heritage.

7.1.7 Economic Impact

Livestock integration can have positive economic impacts in highlands by:

(1) **Increasing income generation:** Livestock products, such as milk, meat, and wool, can provide farmers with additional income sources, improving their economic resilience.
(2) **Enhancing market opportunities:** Livestock integration can create new market opportunities for farmers, especially for high-value products such as organic meat or dairy products.
(3) **Stimulating local economies:** Livestock production can stimulate local economies by creating demand for animal feed, veterinary services, and other inputs.

7.1.8 Other Ecosystem Benefits

Livestock integration can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved soil health:** Livestock grazing, and manure application can improve soil health by increasing organic matter content, promoting microbial activity, and enhancing soil structure.
(2) **Enhanced biodiversity:** Well-managed grazing systems can promote biodiversity by creating diverse habitats for plants and animals.
(3) **Pollination services:** Livestock, such as bees, can provide valuable crop pollination services, improving yields and quality.

7.1.9 Disadvantages and Tradeoffs, if any

Livestock integration may have some disadvantages and tradeoffs, including:

(1) **Overgrazing risk:** Poorly managed grazing can lead to overgrazing, which can degrade soil health, reduce biodiversity, and increase erosion.
(2) **Greenhouse gas emissions:** Livestock production can contribute to greenhouse gas emissions, mainly methane from enteric fermentation and manure management.
(3) **Competition for resources:** Livestock may compete with crops for water and land resources, especially in areas with limited resources.

7.1.10 Other Information

Livestock integration is a complex practice that requires careful planning and management to maximize its benefits and minimize its negative impacts. Successful livestock integration involves selecting appropriate animal species, implementing sustainable grazing practices, and managing manure effectively. It also requires collaboration among farmers, researchers, and policymakers to develop and implement policies and practices that support sustainable livestock integration in highland regions.

7.2 Rotational Grazing

7.2.1 Background

Rotational grazing is a livestock management practice that systematically divides pastures into smaller paddocks and rotates livestock between them. This allows for periods of rest and regrowth for the grazed areas, promoting healthier pastures, improved soil health, and increased forage production. In the context of climate change, rotational grazing is considered a climate-smart agricultural (CSA) practice due to its potential to enhance carbon sequestration, improve soil water retention, and reduce greenhouse gas emissions from livestock. This practice is particularly relevant in highland regions, where overgrazing and soil erosion are common challenges and where sustainable livestock management is crucial for livelihoods and food security.

Source: https://images.app.goo.gl/BbXW8132pETpZiFU7

7.2.2 Innovative Features

Traditional rotational grazing practices have evolved to incorporate innovative features that enhance their effectiveness and adaptability to different highland environments. Some of these innovative features include:

(1) **Adaptive multi-paddock grazing:** Dividing pastures into multiple smaller paddocks and adjusting grazing periods based on forage availability, animal needs, and environmental conditions.

(2) **High-density, short-duration grazing:** Grazing livestock at high densities for short durations stimulates plant growth, improves soil aeration, and enhances nutrient cycling.

(3) **Strategic grazing for vegetation management:** Using livestock to control invasive plant species, reduce fire risk, and promote the growth of desirable forage species.

(4) **Integration with other CSA practices:** Combining rotational grazing with other CSA practices, such as cover cropping, agroforestry, and water harvesting, can help create a more holistic and sustainable farming system.

7.2.3 Contribution to Productivity Improvement

Rotational grazing can contribute to productivity improvement in highlands in several ways:

(1) **Increased forage production:** By allowing pastures to rest and regrowth, rotational grazing can increase forage production and quality, leading to healthier and more productive livestock.
(2) **Improved soil health:** Rotational grazing can improve soil health by increasing organic matter content, promoting microbial activity, and enhancing soil structure.
(3) **Reduced weed pressure:** Strategic grazing can help control weeds, reduce resource competition, and improve forage quality.
(4) **Enhanced animal health:** Rotational grazing can improve animal health by reducing parasite loads and providing a more diverse diet.

7.2.4 Contribution to Climate Resilience

Rotational grazing can enhance climate resilience in highlands by:

(1) **Improving soil water retention:** Healthy soils with high organic matter content can hold more water, making pastures more resilient to drought.
(2) **Reducing soil erosion:** Rotational grazing can minimize soil erosion by promoting vegetation cover and minimizing soil disturbance.
(3) **Enhancing carbon sequestration:** Well-managed grazing systems can sequester carbon in the soil, helping to mitigate climate change.
(4) **Promoting biodiversity:** Rotational grazing can create diverse habitats for plants and animals, enhancing ecosystem resilience to climate change.

7.2.5 Contribution to Greenhouse Gas Mitigation

Rotational grazing can contribute to greenhouse gas mitigation by:

(1) **Increasing soil carbon sequestration:** Rotational grazing can increase soil organic matter content, sequester carbon, and reduce carbon dioxide emissions.
(2) **Reducing methane emissions:** Improved grazing management can reduce methane emissions from livestock by promoting efficient digestion and reducing enteric fermentation.
(3) **Minimizing fertilizer use:** Rotational grazing can reduce the need for synthetic fertilizers by improving soil fertility through natural processes.

7.2.6 Social Impact

Rotational grazing can have positive social impacts in highlands by:

(1) Improving livelihoods: Rotational grazing can increase livestock productivity and income, improving livelihoods for farmers and their families.
(2) **Enhancing food security:** Rotational grazing can contribute to food security by providing a sustainable source of meat and dairy products.
(3) **Promoting sustainable land management:** Rotational grazing can promote sustainable land management practices, contributing to highland ecosystems' long-term health and productivity.

7.2.7 Economic Impact

Rotational grazing can have positive economic impacts in highlands by:

(1) **Increasing livestock productivity:** Rotational grazing can improve livestock health, growth rates, and reproductive performance, increasing productivity and profitability.
(2) **Reducing input costs:** Rotational grazing can reduce the need for supplemental feed, fertilizers, and veterinary treatments, lowering input costs for farmers.

(3) **Improving land value:** Rotational grazing can improve the long-term productivity and value of land by enhancing soil health and forage production.

7.2.8 Other Ecosystem Benefits

Rotational grazing can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved biodiversity:** Rotational grazing can create diverse habitats for plants and animals, promoting biodiversity and ecological balance.
(2) **Enhanced water quality:** Rotational grazing can reduce nutrient runoff and soil erosion, improving water quality in rivers and streams.
(3) **Increased wildlife habitat:** Rotational grazing can provide habitat and food sources for various wildlife species.

7.2.9 Disadvantages and Tradeoffs, if any

Rotational grazing may have some disadvantages and tradeoffs, including:

(1) **Infrastructure costs:** Implementing rotational grazing may require additional fencing and water infrastructure, which can be costly for some farmers.
(2) **Management complexity:** Rotational grazing requires careful planning and management to ensure that grazing periods and stocking rates are appropriate for the specific conditions.
(3) **Potential for overgrazing:** If not appropriately managed, rotational grazing can still lead to overgrazing, damaging pastures and reducing their productivity.

7.2.10 Other Information

Rotational grazing is a versatile and adaptable CSA practice that can be tailored to different highland regions' specific needs and conditions. It can be implemented on a small scale by individual farmers or on a larger scale through community-based grazing schemes. The success of rotational grazing depends on careful planning, appropriate stocking rates, and adaptive management practices.

7.3 Silvopasture

7.3.1 Background

Silvopasture is the intentional integration of trees and shrubs into grazing systems. This agroforestry practice combines forestry and grazing of domesticated animals in a mutually beneficial way. Trees and shrubs provide shade, shelter, and fodder for livestock, while livestock grazing can help control vegetation, improve soil fertility, and enhance carbon sequestration. Silvopasture is particularly well-suited for highland regions, where diverse landscapes and varying climatic conditions can support a wide range of tree and forage species. This practice can enhance the productivity and sustainability of livestock systems while providing numerous environmental benefits.

Source: https://images.app.goo.gl/9egJhZs1DVfeP9rJ9

7.3.2 Innovative Features

Silvopasture systems in highlands can be designed to incorporate innovative features that optimize their productivity, resilience, and environmental benefits. Some of these innovative features include:

(1) **Multi-species Silvopasture systems:** Combining different tree and shrub species with varying growth habits and forage values to create a diverse and resilient system.
(2) **Alley cropping with Silvopasture:** Integrating alley cropping, where crops are grown between rows of trees, with Silvopasture to provide additional income sources and improve soil fertility.
(3) **Managed grazing systems:** Implementing rotational or strip grazing to optimize forage utilization, improve animal health, and enhance soil health.
(4) **Tree fodder production:** Selecting tree and shrub species that provide high-quality fodder for livestock, supplementing traditional forage sources and improving animal nutrition.

(5) **Integration with water harvesting:** Incorporating water harvesting techniques, such as swales or ponds, into Silvopasture systems to improve water availability for livestock and enhance drought resilience.

7.3.3 Contribution to Productivity Improvement

Silvopasture can contribute to productivity improvement in highlands in several ways:

(1) **Increased forage production:** Trees and shrubs can improve forage production by providing shade, reducing heat stress on grasses, and enhancing soil fertility.
(2) **Improved forage quality:** Tree and shrub leaves and pods can provide a valuable source of protein and other nutrients for livestock, improving their health and productivity.
(3) **Enhanced animal welfare:** Shade and shelter provided by trees and shrubs can improve animal welfare by reducing heat stress and providing protection from harsh weather conditions.
(4) **Diversified income sources:** Silvopasture systems can provide farmers with additional income sources from tree products, such as timber, fruits, and nuts.

7.3.4 Contribution to Climate Resilience

Silvopasture can enhance climate resilience in highlands by:

(1) **Mitigating drought:** Trees and shrubs can help conserve soil moisture and reduce plant water stress, making Silvopasture systems more resilient to drought.
(2) **Reducing heat stress:** Shade provided by trees and shrubs can reduce heat stress on livestock, improving their health and productivity.
(3) **Protecting against soil erosion:** Trees and shrubs can help to stabilize slopes and reduce soil erosion caused by heavy rainfall and wind.
(4) **Enhancing carbon sequestration:** Silvopasture systems can sequester carbon in both trees and soil, contributing to climate change mitigation.

7.3.5 Contribution to Greenhouse Gas Mitigation

Silvopasture can contribute to greenhouse gas mitigation by:

(1) **Carbon sequestration:** Trees and shrubs in Silvopasture systems can absorb carbon dioxide from the atmosphere and store it in their biomass and soil, reducing greenhouse gas concentrations.
(2) **Reduced methane emissions:** Improved grazing management in Silvopasture systems can reduce methane emissions from livestock by promoting efficient digestion and reducing enteric fermentation.
(3) **Reduced nitrous oxide emissions:** Silvopasture systems can improve nitrogen use efficiency in the soil, reducing the risk of nitrous oxide emissions from excess nitrogen in manure.

7.3.6 Social Impact

Silvopasture can have positive social impacts in the highlands by:

(1) **Improving livelihoods:** Silvopasture can increase livestock productivity and income, leading to improved livelihoods for farmers and their families.
(2) **Enhancing food security:** Silvopasture can contribute to food security by providing a sustainable source of meat and dairy products.
(3) **Promoting sustainable land management:** Silvopasture can promote sustainable land management practices, contributing to highland ecosystems' long-term health and productivity.

7.3.7 Economic Impact

Silvopasture can have positive economic impacts in the highlands by:

(1) **Increasing livestock productivity:** Silvopasture can improve livestock health, growth rates, and reproductive performance, increasing productivity and profitability.
(2) **Reducing input costs:** Silvopasture can lessen the need for supplemental feed, fertilizers, and veterinary treatments, lowering input costs for farmers.
(3) **Diversifying income sources:** Silvopasture systems can provide farmers with additional income sources from tree products, such as timber, fruits, and nuts.

7.3.8 Other Ecosystem Benefits

Silvopasture can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved biodiversity:** Silvopasture systems can support a greater diversity of plant and animal species compared to monoculture grazing systems.
(2) **Enhanced water quality:** Trees and shrubs in Silvopasture systems can help filter runoff water and reduce sediment and nutrient pollution in rivers and streams.
(3) **Increased wildlife habitat:** Silvopasture systems can provide habitat and food sources for various wildlife species, including birds, insects, and small mammals.

7.3.9 Disadvantages and Tradeoffs, if any

Silvopasture may have some disadvantages and tradeoffs, including:

(1) **Establishment costs:** Establishing a Silvopasture system can require significant upfront investment in tree planting and fencing.
(2) **Management complexity:** Silvopasture systems require careful management to balance the needs of trees, shrubs, and livestock.
(3) **Potential for competition:** Trees and shrubs may compete with grasses for water and nutrients, especially in the early stages of establishment.

7.3.10 Other Information

Silvopasture is a versatile and adaptable CSA practice that can be tailored to the specific needs and conditions of different highland regions. It can be implemented on a small scale by individual farmers or on a larger scale through community-based initiatives. The success of Silvopasture depends on careful planning, appropriate species selection, and adaptive management practices.

8. Other Highland CSA Practices

8.1 Agroforestry

8.1.1 Background

Agroforestry is a land management system integrating trees and shrubs into crops and animal farming systems. It has been practiced for centuries in different parts of the world and is recognized for its multiple benefits, including enhanced productivity, improved soil health, and increased biodiversity. In the context of climate change, agroforestry is gaining attention as a climate-smart agricultural (CSA) practice due to its potential to address the challenges posed by a changing climate.

Source: https://www.aciar.gov.au/media-search/blogs/agroforestry-helps-farmers-make-greener-land-and-better-life

8.1.2 Innovative Features

Agroforestry systems in highlands can be designed to include a variety of tree and shrub species that are well-suited to the region's specific climatic and soil conditions. These species can be selected for their ability to provide multiple benefits, such as nitrogen fixation, soil erosion control, and carbon sequestration. Innovative agroforestry practices in highlands may involve the use of:

(1) **Multi-strata systems:** Combining trees of different heights and growth habits to maximize light interception and resource utilization.
(2) **Alley cropping:** Planting crops between rows of trees or shrubs improves soil fertility and reduces erosion.
(3) **Silvopasture:** Integrating trees and shrubs into grazing systems to provide shade, fodder, and shelter for livestock.

8.1.3 Contribution to Productivity Improvement

Agroforestry can contribute to productivity improvement in highlands in several ways:

(1) **Improved soil fertility:** Trees and shrubs can add organic matter, improve soil structure, enhance nutrient cycling, and increase crop yields.
(2) **Reduced soil erosion:** Trees and shrubs can help reduce soil erosion caused by wind and water, thereby conserving topsoil and nutrients.
(3) **Enhanced water availability:** Trees and shrubs can help regulate water flow, improve infiltration, and reduce evaporation, leading to increased water availability for crops.
(4) **Diversified income sources:** Agroforestry systems can provide farmers additional income from tree products, such as fruits, nuts, timber, and fodder.

8.1.4 Contribution to Climate Resilience

Agroforestry can enhance climate resilience in highlands by:

(1) **Providing shade and windbreaks:** Trees and shrubs can protect crops and livestock from extreme temperatures, strong winds, and heavy rainfall.
(2) **Improving soil water retention:** Agroforestry systems can help to improve soil water retention, making crops more resilient to drought.
(3) **Reducing vulnerability to pests and diseases:** The increased biodiversity in agroforestry systems can help reduce crops and livestock's vulnerability to pests and diseases.

8.1.5 Contribution to Greenhouse Gas Mitigation

Agroforestry can contribute to greenhouse gas mitigation by:

(1) **Sequestering carbon:** Trees and shrubs can absorb carbon dioxide from the atmosphere and store it in their biomass and soil, thereby reducing greenhouse gas concentrations.
(2) **Reducing emissions from deforestation:** Agroforestry can provide an alternative to deforestation for agricultural expansion, thereby reducing greenhouse gas emissions from land-use change.
(3) **Improving soil carbon storage:** Agroforestry practices can enhance soil carbon storage, further mitigating greenhouse gas emissions.

8.1.6 Social Impact

Agroforestry can have positive social impacts in highlands by:

(1) **Improving livelihoods:** Agroforestry can provide farmers with diversified income sources and improve food security, thereby enhancing livelihoods.
(2) **Empowering women:** Agroforestry can empower women by giving them access to resources and income-generating opportunities.
(3) **Strengthening communities:** Agroforestry can promote participation and collaboration, leading to more robust and resilient communities.

8.1.7 Economic Impact

Agroforestry can have positive economic impacts in highlands by:

(1) **Increasing agricultural productivity:** Agroforestry can increase crop yields and livestock productivity, resulting in higher incomes for farmers.
(2) **Diversifying income sources:** Agroforestry can provide farmers with additional income sources from tree products, reducing their dependence on a single crop or livestock enterprise.
(3) **Creating employment opportunities:** Agroforestry can generate employment opportunities for planting, managing, and processing tree products.

8.1.8 Other Ecosystem Benefits

Agroforestry can provide a range of other ecosystem benefits in highlands, including:

(1) **Biodiversity conservation:** Agroforestry systems can support a greater diversity of plant and animal species than monoculture systems.
(2) **Watershed protection:** Trees and shrubs can help to regulate water flow, reduce erosion, and improve water quality in watersheds.
(3) **Pollination services:** Agroforestry systems can provide habitat for pollinators, which are essential for crop production.

8.1.9 Disadvantages and Tradeoffs, if any

Agroforestry may have some disadvantages and tradeoffs, including:

(1) **Competition for resources:** Trees and shrubs may compete with crops for water, nutrients, and light, especially in the early stages of establishment.
(2) **Increased management complexity:** Agroforestry systems may require more complex management practices than monoculture systems.
(3) **Land tenure issues:** In some cases, land tenure issues may limit the adoption of agroforestry practices.

8.1.10 Other Information

Agroforestry is a versatile and adaptable CSA practice that can be tailored to different highland regions' specific needs and conditions. It can be integrated into various farming systems, including smallholder farms, commercial farms, and community-managed forests. The success of agroforestry depends on careful planning, appropriate species selection, and effective management practices.

8.2 Pest Management

8.2.1 Background

Pest management is a crucial aspect of agricultural production, aiming to minimize the damage caused by pests, such as insects, diseases, and weeds, to crops and livestock. In the context of climate change, pest management is gaining importance as a climate-smart agricultural (CSA) practice due to the increasing prevalence and severity of pest outbreaks associated with changing climatic conditions. Warmer temperatures altered rainfall patterns, and extreme weather events can create favorable environments for pests, leading to increased crop losses and reduced agricultural productivity. Effective pest management strategies are essential for ensuring food security, protecting livelihoods, and promoting sustainable agriculture in highland regions.

Source: https://images.app.goo.gl/vMEk9a5KhhxjrmTz6

8.2.2 Innovative Features

Traditional pest management practices, such as the use of chemical pesticides, have raised concerns about their environmental and health impacts. Innovative pest management approaches are being developed to minimize the use of chemicals and promote ecological balance in highland agroecosystems. Some of these innovative features include:

(1) **Integrated Pest Management (IPM):** IPM is a holistic approach that combines various pest management strategies, such as biological control, cultural practices, and targeted pesticide use, to minimize pest damage while minimizing environmental impact.
(2) **Biological control:** Utilizing natural enemies of pests, such as predators, parasitoids, and pathogens, to control pest populations.
(3) **Cultural practices:** Implementing cultural practices, such as crop rotation, intercropping, and sanitation, to disrupt pest life cycles and reduce their populations.
(4) **Resistant varieties:** Planting crop varieties resistant to specific pests and diseases reduces the need for pesticides.

(5) **Pheromone traps:** Using pheromone traps to monitor pest populations and disrupt their mating behavior.
(6) **Push-pull strategies:** Implementing push-pull strategies involves planting repellent crops to push pests away from the main crop and trap crops to attract them.

8.2.3 Contribution to Productivity Improvement

Effective pest management can contribute to productivity improvement in highlands in several ways:

(1) **Reduced crop losses:** By minimizing pest damage, pest management can significantly reduce crop losses, leading to higher yields and increased farmer income.
(2) **Improved crop quality:** Pest management can improve crop quality by preventing damage to leaves, fruits, and other plant parts, leading to higher market prices and increased profitability.
(3) **Enhanced resource use efficiency:** By reducing the need for pesticides and other inputs, pest management can improve resource use efficiency and lower production costs.

8.2.4 Contribution to Climate Resilience

Pest management can enhance climate resilience in highlands by:

(1) **Reducing vulnerability to pest outbreaks:** Climate change can increase the risk of pest outbreaks, and effective pest management strategies can help to mitigate this vulnerability.
(2) **Protecting crops from climate-related stress:** Pest management can help to protect crops from climate-related stress, such as drought or heat, by reducing their susceptibility to pests and diseases.
(3) **Promoting sustainable agriculture:** By minimizing the use of chemical pesticides, pest management can promote sustainable agricultural practices and protect the environment.

8.2.5 Contribution to Greenhouse Gas Mitigation

Pest management can contribute to greenhouse gas mitigation by:

(4) **Reducing pesticide use:** Chemical pesticides are a significant source of greenhouse gas emissions, and reducing their use can contribute to climate change mitigation.
(5) **Promoting soil health:** Healthy soil can sequester carbon and reduce greenhouse gas emissions; pest management practices promoting soil health can contribute to this process.

8.2.6 Social Impact

Pest management can have positive social impacts in highlands by:

(1) **Improving livelihoods:** By increasing crop yields and reducing losses, pest management can improve the livelihoods of farmers and their families.
(2) **Enhancing food security:** Pest management can contribute to food security by ensuring a stable food supply and reducing the risk of crop failure due to pests and diseases.
(3) **Protecting human health:** By minimizing the use of chemical pesticides, pest management can protect the health of farmers, farmworkers, and consumers.

8.2.7 Economic Impact

Pest management can have positive economic impacts in highlands by:

(1) **Increasing crop yields:** Effective pest management can significantly increase crop yields, leading to higher incomes for farmers.

(2) **Reducing input costs:** By minimizing the use of pesticides and other inputs, pest management can lower production costs for farmers.
(3) **Improving market access:** Pest management can improve market access for farmers by ensuring that their produce meets quality standards and is free from pests and diseases.

8.2.8 Other Ecosystem Benefits

Pest management can provide a range of other ecosystem benefits in highlands, including:

(1) **Protecting biodiversity:** By minimizing the use of broad-spectrum pesticides, pest management can help preserve beneficial insects, pollinators, and other wildlife.
(2) **Enhancing soil health:** Pest management practices that promote soil health, such as cover cropping and crop rotation, can improve soil fertility, structure, and biodiversity.
(3) **Reducing water pollution:** Pest management can reduce pesticide runoff and contamination of water resources, protecting aquatic ecosystems and human health.

8.2.9 Disadvantages and Tradeoffs, if any

Pest management may have some disadvantages and tradeoffs, including:

(1) **Cost and complexity:** Implementing integrated pest management (IPM) strategies can be more complex and costly than relying solely on chemical pesticides.
(2) **Knowledge and skills:** Effective pest management requires knowledge and skills in identifying pests, understanding their biology and behavior, and implementing appropriate control measures.
(3) **Time and labor:** Pest management can be time-consuming and labor-intensive, especially for small-scale farmers with limited resources.

8.2.10 Other Information

Pest management is a critical component of sustainable agriculture in the highlands. It requires a holistic approach that considers pest control's ecological, social, and economic aspects. Farmers can protect their crops, improve their livelihoods, and contribute to climate change mitigation and adaptation by adopting innovative and sustainable pest management practices.

8.3 Windbreaks

8.3.1 Background

Windbreaks, also known as shelterbelts, are rows of trees or shrubs planted perpendicular to the prevailing wind direction. They are a widely used agricultural practice to protect crops, livestock, and soil from the damaging effects of wind. In the context of climate change, windbreaks are gaining recognition as a climate-smart agricultural (CSA) practice due to their potential to reduce wind erosion, conserve soil moisture, moderate microclimates, and enhance biodiversity. These benefits are significant in highland regions, where strong winds, thin soils, and extreme temperatures can pose considerable challenges for agriculture.

Source: https://images.app.goo.gl/kAdri2EyRXNaLAxW6

8.3.2 Innovative Features

Traditional windbreak designs have evolved to incorporate innovative features that enhance their effectiveness and adaptability to different highland environments. Some of these innovative features include:

(1) **Multi-species windbreaks:** Planting a diverse mix of tree and shrub species with varying heights, densities, and root systems creates a more effective barrier against wind and provides multiple ecological benefits.
(2) **Living fences:** Integrating windbreaks with living fences made of fast-growing shrubs or trees to provide additional protection for crops and livestock while also serving as a source of fodder or fuelwood.
(3) **Agroforestry windbreaks:** Combining windbreaks with agroforestry practices, such as alley cropping or silvopasture, to provide additional income sources and ecological benefits.
(4) **Windbreak design software:** Utilizing computer software to model wind flow patterns and optimize windbreak design for maximum effectiveness.

8.3.3 Contribution to Productivity Improvement

Windbreaks can contribute to productivity improvement in highlands in several ways:

(1) **Reduced wind erosion:** Windbreaks significantly reduce wind erosion by decreasing wind speed and trapping soil particles, thereby conserving topsoil and nutrients.
(2) **Improved soil moisture retention:** Windbreaks can reduce evaporation from the soil surface, conserving moisture and making it available for plant growth, especially during dry periods.
(3) **Moderated microclimates:** Windbreaks can create a more favourable microclimate for crops by reducing wind speed, moderating temperature extremes, and increasing humidity.
(4) **Enhanced pollination:** Windbreaks can provide habitat and shelter for pollinators, such as bees and butterflies, improving pollination and higher crop yields.

8.3.4 Contribution to Climate Resilience

Windbreaks can enhance climate resilience in highlands by:

(1) **Protecting against wind damage:** Windbreaks can protect crops and livestock from the damaging effects of strong winds, such as lodging, desiccation, and physical injury.
(2) **Conserving soil moisture:** Windbreaks can reduce evaporation from the soil surface, conserving moisture and making crops more resilient to drought.
(3) **Moderating temperature extremes:** Windbreaks can buffer crops and livestock from extreme temperatures, reducing heat stress and frost damage.
(4) **Enhancing soil health:** Windbreaks can improve soil health by reducing erosion, increasing organic matter content, and promoting microbial activity.

8.3.5 Contribution to Greenhouse Gas Mitigation

Windbreaks can contribute to greenhouse gas mitigation by:

(1) **Increasing carbon sequestration:** Trees and shrubs in windbreaks can absorb carbon dioxide from the atmosphere and store it in their biomass and soil, reducing greenhouse gas concentrations.
(2) **Reducing energy consumption:** Windbreaks can reduce energy consumption for heating and cooling in buildings and livestock shelters, leading to lower greenhouse gas emissions.

8.3.6 Social Impact

Windbreaks can have positive social impacts in highlands by:

(1) **Improving livelihoods:** Windbreaks can increase agricultural productivity and income, improving livelihoods for farmers and their families.
(2) **Enhancing food security:** Windbreaks can contribute to food security by protecting crops from wind damage and improving yields.
(3) **Protecting infrastructure:** Windbreaks can protect buildings, roads, and other infrastructure from wind damage, reducing maintenance costs and improving safety.

8.3.7 Economic Impact

Windbreaks can have positive economic impacts in highlands by:

(1) **Increasing crop yields:** Windbreaks can improve crop yields by reducing wind damage, conserving soil moisture, and moderating microclimates.
(2) **Reducing input costs:** Windbreaks can lessen the need for irrigation, pesticides, and fertilizers, lowering input costs for farmers.
(3) **Providing additional income sources:** Windbreaks can provide additional income sources from tree products, such as timber, fuelwood, and fruits.

8.3.8 Other Ecosystem Benefits

Windbreaks can provide a range of other ecosystem benefits in highlands, including:

(1) **Improved biodiversity:** Windbreaks can provide habitat and food sources for various wildlife species, including birds, insects, and small mammals.
(2) **Enhanced water quality:** Windbreaks can reduce sediment and nutrient runoff from agricultural fields, improving water quality in rivers and streams.
(3) **Reduced noise pollution:** Windbreaks can act as a barrier against noise pollution, creating a more peaceful and enjoyable environment for people and animals.

8.3.9 Disadvantages and Tradeoffs, if any

Windbreaks may have some disadvantages and tradeoffs, including:

(1) **Land requirements:** Windbreaks require land that could otherwise be used for crop production.
(2) **Establishment costs:** Establishing windbreaks can be costly, especially for large-scale projects.
(3) **Maintenance requirements:** Windbreaks require regular maintenance, such as pruning and thinning, to ensure their effectiveness.

8.3.10 Other Information

Windbreaks are a valuable CSA practice that can be adapted to various highland environments and farming systems. Individual farmers can implement them on a small scale or on a larger scale through community-based projects. The success of windbreaks depends on careful planning, appropriate species selection, and ongoing maintenance.

9. Epilogue: The Future of Climate-Smart Agriculture in Highlands

Bua Yai Subdistrict, Na Noi District, Nan Province*: TA Consultant team at the site of keyline ploughing. Source: Authors.*

Climate-smart agriculture (CSA) is not a one-size-fits-all solution but a dynamic and evolving approach that requires continuous adaptation and innovation. As climate change continues to unfold, new challenges and opportunities will arise, necessitating the development of new CSA practices and technologies. The future of CSA in the highlands will depend on several key factors:

(1) **Research and Innovation:** Continued research is essential to identify and develop new CSA practices and technologies that are effective, affordable, and adaptable to the specific conditions of different highland regions. This includes research on crop varieties, livestock breeds, soil management techniques, water conservation strategies, and pest and disease control methods.

(2) **Capacity Building:** Building the capacity of farmers, extension workers, and other stakeholders is crucial for successfully adopting and implementing CSA practices. This includes training on CSA techniques, providing access to information and resources, and fostering knowledge sharing and collaboration among farmers and researchers.

(3) **Policy and Institutional Support:** Supportive policies and institutions are essential for creating an enabling environment for CSA adoption. This includes policies that

incentivize sustainable agricultural practices, provide access to credit and insurance, and support research and development of CSA technologies.

(4) **Market Development:** Creating market demand for CSA products can incentivize farmers to adopt these practices. This can be achieved through certification schemes, labelling programs, and public procurement policies favoring sustainable agricultural products.

(5) **Community Engagement:** Engaging local communities in designing and implementing CSA projects is crucial for ensuring their relevance and sustainability. This includes involving farmers in decision-making processes, respecting traditional knowledge and practices, and addressing different social groups' specific needs and priorities.

The future of CSA in the highlands also holds several promising trends and opportunities:

(1) **Digital Agriculture:** The increasing availability of digital technologies, such as mobile phones, sensors, and drones, is transforming agriculture in the highlands. These technologies can be used to collect and analyze data on soil conditions, crop growth, and weather patterns, enabling farmers to make more informed decisions about their farming practices. Digital platforms can also facilitate farmers in remote areas' access to markets, information, and financial services.

(2) **Climate Information Services:** Climate modelling and forecasting advances provide farmers with more accurate and timely information about weather patterns, climate risks, and potential impacts on their crops and livestock. This information can help farmers make better decisions about planting, harvesting, and other agricultural activities, reducing their vulnerability to climate variability and change.

(3) **Nature-Based Solutions:** Nature-based solutions, such as agroforestry, riparian buffer, grass waterways, conservation agriculture, and integrated pest management, are gaining recognition for their potential to enhance agricultural resilience, improve ecosystem services, and mitigate climate change. These solutions can provide multiple benefits, such as soil conservation, water management, biodiversity conservation, and carbon sequestration.

(4) **Circular Economy:** The concept of a circular economy, which emphasizes minimizing waste and maximizing resource use efficiency, is increasingly being applied to agriculture. This includes practices such as composting, anaerobic digestion, biodegradable materials and using bio-based fertilizers and pesticides. By closing nutrient loops and reducing waste, circular agriculture can contribute to climate change mitigation and improve the sustainability of farming systems.

(5) **Climate Finance:** The growing awareness of the importance of climate action is leading to increased investment in climate finance, including funding for CSA projects in developing countries. This can provide farmers with the necessary resources to adopt CSA practices and technologies, contributing to climate change adaptation and mitigation.

The challenges facing highland agriculture are complex and multifaceted, but the potential of CSA to transform these systems is immense. By embracing innovation, investing in capacity building, and creating an enabling environment for CSA adoption, we can ensure that highland communities are equipped to adapt to climate change, improve their livelihoods, and contribute to a more sustainable and resilient future for all.

9.1.1 The way forward

This compendium has provided a comprehensive overview of various climate-smart agricultural practices that can be applied in highland regions. These practices offer a range of benefits, including increased productivity, enhanced resilience to climate change, and reduced greenhouse gas emissions. By adopting these practices, farmers in highlands can adapt to the changing climate and contribute to global efforts to mitigate climate change and promote sustainable development.

The successful scaling and long-term sustainability of climate-smart agriculture (CSA) in highland regions require a multi-stakeholder approach. Strong collaboration between the public sector, private enterprises, development partners, and international organizations will be crucial in driving the adoption and expansion of CSA practices.

- **Public Sector Involvement**: National and local governments play a key role in creating an enabling environment for CSA adoption. Policies and regulatory frameworks must prioritize CSA integration into broader agricultural development strategies, ensuring farmers can access financial incentives, risk mitigation schemes, and support services. Public-sector investments in research, extension services, and infrastructure—such as improved irrigation systems and rural roads—will enhance the viability of CSA practices.
- **Private Sector Engagement**: The private sector can accelerate CSA adoption through investments in climate-smart technologies, market-driven innovations, and sustainable supply chains. Agribusinesses, financial institutions, and technology providers have a role in delivering CSA inputs, financing solutions, and market access for climate-smart products. Encouraging public-private partnerships (PPPs) will help bridge knowledge, funding, and infrastructure gaps, fostering a more resilient and market-oriented agricultural system in highland regions.
- **Role of Development Partners**: Development organizations, research institutions, and civil society groups provide critical support in advancing CSA implementation. Their role includes funding pilot projects, conducting impact assessments, and facilitating farmer capacity-building initiatives. These partners can also support local governments in designing context-specific CSA policies and interventions, ensuring that CSA solutions are technically viable and socially inclusive.
- **International Partnerships for Scaling Up CSA**: Cross-border collaboration and knowledge-sharing among international stakeholders will strengthen CSA resilience across highland regions. Regional and global initiatives can provide access to climate finance mechanisms, facilitate technology transfer, and establish research partnerships to advance innovation in CSA. By leveraging international networks, policymakers and practitioners can gain valuable insights into best practices, lessons learned, and successful CSA models from other parts of the world.

The future of highland agriculture depends on our ability to adapt to and mitigate the impacts of climate change. Climate-smart agriculture offers a promising pathway towards achieving this goal. By investing in CSA research, capacity building, and policy support, we can empower highland communities to build resilient and sustainable agricultural systems that can thrive in the face of a changing climate.

Bua Yai Subdistrict, Na Noi District, Nan Province*: Local farmers at after preparing microbial fertilizers for soil nutrition enhancement. Source: Authors.*

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