Department of Agriculture
Ministry of Agriculture and Livestock
Royal Government of Bhutan

Climate-Smart Agriculture Technologies and Practices in Bhutan

Consortium for Scaling-up Climate Smart Agriculture in South Asia (C-SUCSeS) Project

(IFAD Grant No. 2000001968)

SAARC Agriculture Centre
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Inventory of Climate-Smart Agriculture (CSA) Technologies and Practices in Bhutan was conducted as one of the activities under the project Consortium for Scaling up Climate-Smart Agriculture in South Asia (C-SUCSeS) of SAARC Agriculture Centre in 2022.

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Foreword

Bhutanese agriculture system has undergone many changes and evolved over time, gradually transitioning towards a commercial-based farming system. Despite this transition since the start of planned agriculture development in the 1960s, about 49% of the Bhutanese populace still depend on agriculture for livelihood.

Various interventions and support from the Royal Government of Bhutan and other development partners have contributed significantly towards the growth of the agriculture sector over time. The Department of Agriculture continues to support and facilitate the development of the agriculture sector intended to achieve food and nutritional security in the country. Despite the efforts, we continue to grapple with many challenges unique to Bhutanese agriculture, and climate change always prominent itself as a major challenge.

In line with the global trend, climate change poses huge challenges to the agriculture system in Bhutan. Hence building resilience to climate change through climate change adaptation and mitigation remains a priority for the Department of Agriculture. Hence, I am pleased to introduce the Inventory of Climate Smart Agriculture (CSA) Technologies and Practices in Bhutan, which attempts to stocktake the available climate-smart agriculture technologies in Bhutan.

Climate-smart technologies in Bhutan target achieving all three pillars of CSA. It also provides a detailed description of the available CSA technology with information on appropriate contact points for more details.

Finally, I would like to request all the valuable readers to use the information in this document for building climate resilience in the agriculture sector, within and outside the country.

TASHI DELEK!

Yonten Gyamtsho
Director, DOA

Preface

In an era, fraught with the challenges of adapting to erratic climatic conditions, rising temperatures, and shifting precipitation patterns, traditional farming practices find themselves at a crossroads. The imperative for innovative solutions becomes paramount – not only to ensure food security but also to mitigate the adverse environmental impacts of agriculture.

This inventory stands as a testament to the ingenuity required in such a scenario. Encompassing an array of technologies and innovative approaches, it addresses the pressing need for productivity, resilience, and sustainability in agricultural systems. Representing a comprehensive collection of the latest methodologies, practices, and technologies, it emerges as a reliable bulwark in the face of climate change's uncertainties.

The CSA technologies featured within this inventory are a testament to collaborative efforts, uniting the contributions of researchers, farmers, and entrepreneurs. Their collective dedication reflects a shared commitment to discovering practical and scalable solutions that confront the risks posed by our changing climate.

Ultimately, this inventory becomes a beacon of knowledge, shedding light on the dynamic landscape of Climate-Smart Agriculture in Bhutan. It doesn't merely present an assortment of technologies; rather, it charts a path toward a more sustainable, resilient, and prosperous agricultural system in Bhutan.

Authors

Acknowledgement

Inventory of Climate Smart Agriculture (CSA) Technologies and Practices in Bhutan attempts to stock take all the climate-smart agriculture technologies and practices initiated in Bhutan. Furthermore, the inventory provides detailed information on individual technologies with information on their suitability and sustainability.

The inventory is a combined effort of all the researchers and inventors from within the Department of Agriculture and outside. Hence, the Department of Agriculture would like to acknowledge the combined effort of everyone involved in the process of vectorization and implementation of these CSA technologies. The department would also like to extend its acknowledgment to the following contributing authors involved:

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Abbreviations/Acronyms

ALD: Agriculture Land Development
AMTC: Agriculture Machinery and Technology Centre
APD: Agriculture Production Division
ARDC: Agriculture Research and Development Centre
ARID: Agriculture Research and Innovation Division
BAMS: Bhutan Agriculture Microbial Solution
BPDP: Bhutan Potato Development Project
BTFEC: Bhutan Trust Fund for Environmental Conservation
CARLEP: Commercial Agriculture and Resilient Livelihoods Enhancement Program
CSA: Climate Smart Agriculture
CTV: Citrus Tristeza Virus
DBT: Department of Biotechnology
DoA: Department of Agriculture
EF: Electric Fencing
EM: Effective Microorganisms
FCBL: Food Corporation of Bhutan Limited
FSAPP: Food Security and Agriculture Productivity Project
GDP: Gross Domestic Product
GHG: Greenhouse Gas
GIS: Geographic information system
GPS: Global Positioning System
HFPU: Homogeneous field productive unit
HLB: Huanglongbing
HM: Hybrid Maize
HTMA: Heat-Tolerant Maize for Asia
HWC: Human-Wildlife Conflict
ICIMOD: International Centre for Integrated Mountain Development
IFFCO: Indian Farmers Fertiliser Cooperative
IoT: Internet of Things
IPM: Integrated Pest Management
LFS: Labour Force Survey
MOV: Model Organic Village
MS: Mild Steel
NCOA: National Centre for Organic Agriculture
NFT: Nutrient Film Technique
NMC: National Mushroom Centre
NPPC: National Plant Protection Centre
NSC: National Seed Centre
NSSC: National Soil Service Centre
PEF: Portable Electric Fence
RAMCO: Regional Agricultural Marketing and Cooperatives Office
RNR: Renewable Natural Resource
RNR: Renewable Natural Resources
SIT: Smart Irrigation Technology
SLM: Sustainable Land Management
SSNM: Site-Specific Nutrient Management
UHDP: Ultra-High-Density Plantation

Introduction

Bhutan is an agrarian country providing livelihoods to 49% (LFS, 2021) of its total population from agriculture. The majority of the farming community in the country practices self-sustaining and sustainable farming owing to the small, scattered, and marginal landholdings. Arable land is scarce, amounting to 2.7% of the total land area of the country's territory, of which 133,764 acres (53.49% of total arable land), are operational dryland, 41,145.86 acres (16.45% of total arable land) are operational wetland and 6707.20 acres (2.68% of the total arable land) are operational orchard land. Despite the limited land available for cultivation, land productivity in terms of value has been increasing over the years. The contribution towards GDP from the RNR sector (Agriculture, Livestock, and Forestry) has increased to 19.23% in 2020 from 14.78% in 2010. Of the other RNR sectors of the country, agriculture alone contributes about 10.64% to the total GDP (Gross Domestic Product) of the country. The major RNR activity is dominated by 'crop production' at 56.39% followed by crop and livestock production at 38.51% (RNR Census Report, 2019). Regardless, farming in Bhutan is mostly small-scale and dominated by rainfed dryland and wetland farming.

Agriculture in Bhutan is affected by various challenges. Of the total cultivable land of 250,062 acres, nearly 26.36% (65,922.02 acres) is left fallow due to diverse factors conflicting with agricultural activities. Scattered and small landholdings, water scarcity, human-wildlife conflict, rural-urban migration, labour shortages, market access barriers, lack of access to technologies, and climate change are the most pertinent factors limiting agricultural activities in the country. Agriculture remains dominated by rainfed drylands and wetland farming as most of the water sources are dependent on monsoon rainfalls. Further, water shortages limit orchard development, vegetable production, and feed production.

In the course of the past few years, the country has been affected by rapid changes in the average temperatures, patterns of precipitation, and increased risks of other climatic changes, including excessive rainfall, flash floods, windstorms, hailstorms, and droughts causing massive damage and losses to the farming communities. Most of the farmers are entirely dependent on the monsoons for irrigation. The late arrival of the monsoon due to changes in precipitation patterns can lead to drought, while excessive monsoon rains cause natural disasters, such as landslides and floods. Such changes in climatic events not only affect the production of farming communities but also put them at higher risk as many remain isolated in areas prone to such hazards. The effects of climate change – altered water availability, increasing temperatures during both day and night time, extreme weather events such as cold snaps and giant hailstones, and shifts in the agroecological zones are already impacting Bhutan's agricultural productivity. Given the nation's socio-economic dependence on agriculture, the effects of climate change are proving to be a grave threat to the agriculture sector.

There are more than 40 released climate-smart agriculture technologies and practices in Bhutan. The technologies are disseminated to the farmers at varying scales depending upon the profitability and convenience.

Purpose of the CSA Inventory

The Department of Agriculture has released CSA technologies in Agriculture Research and Development Centres (ARDC) and Central Programs. Most of the technologies remain shelved in individual agencies in the absence of a common platform for inventory. There are also some inventories restricted to particular purposes with different ownerships serving different donor agencies. Those inventories remained either unknown or insufficient or not reliable for making decisions on scalability.

This inventory brings together a wide range of released, viable, and profitable technologies, providing sufficient choice to transform the current practice of agriculture into climate-smart agriculture. The identified CSA technologies will give a wide range of choices for the selection of visible and promising technologies for participatory research which will ultimately contribute to scaling up under the C-SUCSeS project. The best CSA technologies and practices suitable for smallholders, particularly women farmers are identified and scaled up in the country.

The inventory provides basic information/data on all released technologies, which will serve as a useful reference for researchers, policymakers, and regulatory authorities in the country. It will also act as a guiding document for other projects and implementation at large.

CSA Inventory Approach and Methodology

The inventory on climate-smart agriculture technologies is developed through the identification of agriculture technologies that can be qualified as climate-smart agriculture. The CSA technologies are qualified for three pillars viz productivity, adaptability, and reduced emissions of greenhouse gases. All identified technologies are either released in Research Centres or Central Programs and are mostly in the developing phase.

A standard structure for CSA inventory was developed which was validated and recommended by all SAARC member countries. The standard structure was finalized and endorsed by agriculture experts from various agencies and management in Bhutan.

Following the endorsement, a series of virtual consultation meetings and desk research were conducted to identify CSA technologies in different regions. Details of the individual technology including the assessment of smartness of CSA technologies as per the approved format were provided by the relevant agriculture experts in the ARDCs and Central Programs.

Figure 1. Writeshop on CSA inventory at Serbithang, Thimphu

Brief on Climate-Smart Agriculture

The CSA technologies aim at improving crop productivity to improve livelihoods and make farmers more resilient to climate change impacts that they are facing now and to those likely to hit in the future, and where feasible, curb greenhouse gas emissions associated with growing food. The pillars of CSA are as follows:

- **Sustainably increase agricultural productivity and income:** To produce more and better food to improve nutrition security and boost incomes, especially for 75 percent of the world's poor who live in rural areas and mainly rely on agriculture for their livelihoods.
- **Adapt and build the resilience of people and food systems to climate change:** Reduce vulnerability to drought, pests, diseases, and other climate-related risks and shocks; and improve capacity to adapt and grow in the face of longer-term stresses like shortened seasons and erratic rainfall patterns.
- **Reduce and/or remove greenhouse gas emissions:** Pursue lower emissions for each calorie or kilo of food produced, avoid deforestation from agriculture, and identify ways to absorb carbon out of the atmosphere.

The various climate-smart agriculture technologies, practices, and services identified by the Department of Agriculture are further divided into six categories depending upon their ability to respond to the effects of climate change, adaptability, and contribution to reducing or removing greenhouse gas emissions. The different CSA technologies, practices, and services are detailed below:

Table 1. Assessment of smartness of CSA technologies

SN	CSA Technology	Weather Smart	Water Smart	Carbon Smart	Nutrient Smart	Energy Smart	Knowledge Smart
1	Mulching		✓		✓		
2	Intercropping				✓		
3	Rain shelter for vegetable cultivation	✓					✓
4	Crop rotation				✓		✓
5	Arecanut based multi-tier cropping system	✓			✓		

SN	CSA Technology	Weather Smart	Water Smart	Carbon Smart	Nutrient Smart	Energy Smart	Knowledge Smart
6	Ultra high-density fruit plantation in mango and apple	✓			✓		
7	Protected cultivation		✓				
8	Drum seeder			✓			
9	Sustainable water management (electric water pump)		✓				
10	Sustainable land management			✓			
11	Site specific nutrient management				✓		
12	Nano fertilizers				✓		
13	Integrated Pest Management (IPM)	✓	✓	✓			
14	Bioacoustics system						✓
15	ePest surveillance system						✓
16	Biopesticide			✓			
17	Smart Electric Fencing			✓			✓
18	Google Assistance in Agriculture						✓
19	Shoot tip grafting In-Vitro						✓
20	Heat Tolerant maize	✓					
21	Automated/Smart Irrigation Technology (SIT)		✓				✓
22	Low-cost Bamboo greenhouse	✓					
23	Heat tolerant vegetables	✓					
24	Spring Paddy	✓					
25	Upland Paddy	✓					
26	Sunken greenhouse	✓					
27	Chatbot Technology in Agriculture	✓					✓
28	Hydroponics		✓		✓		
29	Rangzhin Bupmen (Bio-pesticide)				✓		
30	Rangzhin luechu 1 (Bio-fertilizer)				✓		
31	Vermicomposting				✓		
32	Composting				✓		
33	Aeroponics	✓	✓		✓		✓
34	Tissue Culture	✓	✓		✓		✓
35	Low-cost plastic lined water harvesting pond		✓				
36	Rice-bran Bokashi			✓	✓		
37	Bhutan Agriculture Microbial Solution				✓		

The CSA technologies included in the inventory are released technologies from ARDCs and Central Programs. Most of the technologies are promoted in the farmers' fields, creating a visible impact on the development of the agriculture sector. From the inventory, a few technologies will be further studied for viability and scalability through participatory research under the C-SUCSeS project.

Brief Description of Individual CSA Technology

1. Mulching

Mulching is a method of covering the soil/ground with plastic and plant materials such as straw, dead leaves, husks, and others to make favorable conditions for crop production. Plant residues were used for mulching traditionally and are already practiced all over the country. For example, mulching with chopped artemisia plants in chili fields is a very popular method in the western and eastern parts of Bhutan. In the past few years, the use of plastic mulching has gained prominence and is now widely practiced in vegetable cultivation.

Figure 2. Plastic mulch in Chilli cultivation (L) and Beans cultivation (R)

Mulching is generally water and nutrient-smart as it aids in soil moisture retention, improves soil nutrients from the decomposition of mulching materials, prevents topsoil loss, and enhances soil's physical, biological, and physical properties. The advantages of this technology include retention of soil moisture, improvement of soil structure by preventing loss of soil organic matter, controlling soil temperature, and decreasing pest incidences. It is also very efficient in suppressing weeds and suitable in high weed-growing areas. On the downside, inconveniences are encountered during irrigation and fertilizer application.

Mulching, with both plant residues and plastic materials, is suitable for the cultivation of both vegetables and fruit crops. Most vegetable farmers, especially in southern and western districts prefer plastic mulches over plant residues. It is extensively used for the cultivation of off-season chili in these areas. The technology is beneficial to both smallholder and commercial farmers especially to women as mulching suppresses weeds which is generally done by women. Weed control effectiveness through the use of mulch ranges from 75% to 90% with the most effective being the black plastic mulch. Mulching also reduces the residual effects of pesticides, fertilizers, and heavy metals.

The main challenge in scaling up the practice is the high cost of mulching materials which is not affordable by all smallholders. Another growing concern is the residual plastics, which are not degradable and may have a detrimental effect on the environment, therefore, the use of biodegradable mulching materials is recommended.

2. Intercropping

Intercropping is the practice of growing two or more crops together. This is practiced mainly to derive a greater yield from a given piece of land by making optimum use of all the available resources that would otherwise not be exploited to full by growing a single crop alone. The practice of intercropping has been around for ages in the Bhutanese farming system. The growing together of different vegetables, maize and potato, paddy and legumes, vegetables inside fruit orchards, etc. are commonly practiced.

Figure 3. Maize-Chilli intercropping system (L) and Cole crops intercropping in Apple orchard (R)

The practice is nutrient-smart as it has the potential to increase soil fertility, enhance overall yields, decrease pest incidence, and eventually reduce the effects of climate change. Intercropping helps to protect soil from extreme erosion, improves soil structure, enhances the soil fertility status where legumes are incorporated, conserves moisture, and suppresses pests and pathogens. It thus enables more effective and efficient utilization of limited resources. The technology is beneficial mainly to the smallholders. This system reduces the risk of crop failure and ensures food security for smallholders as in the case of loss of one crop, the farmers can still rely on the other crop for food and income. It offers equal benefits to both genders to diversify crops and increase income. However, the intercropping system is labour intensive, poses problems in carrying out intercultural operations and mechanization, and has the potential for competitive effects among the component crops.

The multiple cropping practices are dominated by traditional technologies and refined by farmers through their experiences. Some of the intercropping practices like growing paddy with legumes and maize with potatoes have been widely practiced in the southern and eastern parts of Bhutan for centuries Potato and maize intercropping is the most established intercropping practiced by the Bhutanese farmers in maize production zone II (1200- 1800 m asl) and highland maize production zone (above 1800- 2700 masl) in the rainfed drylands. Maize-potato intercropping practice is most popular in the altitude range of 1200- 2400 masl and constitutes 35% of the total potato area in the country. In this system, potato (the main crop) is planted in February within ridges, and maize is sown in the furrows in March. Potatoes and Maize are harvested in July and September respectively.

The technology is beneficial mainly to the smallholders. This system reduces the risk of crop failure and ensures food security for smallholders as in the case of loss of one crop, the farmers can still rely on the other crop for food and income. It offers equal benefits to both genders to diversify crops and increase income. However, the intercropping system is labour intensive, poses problems in carrying out intercultural operations and mechanization, and has the potential for competitive effects among the component crops.

Some traditional multiple cropping technologies that are well adapted to a locality could be refined and exploited to adapt against the potential threats of climate change to make it more efficient, acceptable, and cost-effective mechanisms for climate-smart agriculture. There is limited research focus and a lack of comprehensive manuals and other technical materials on the establishment, operations, and management practices of intercropping.

3. Rain shelter for vegetable cultivation

Rain shelters are structures resembling a greenhouse with roofs for protection and open side walls. The frames are made using locally available materials such as GI pipes, wood, or bamboo poles and are covered with transparent UV-stabilized low-density polyethylene film. Ideally, transparent UV-stabilized polyethylene sheets with 200-micron thickness are used. There are different types of rain shelters depending on the shape and size of the structure. As such, the roof can be shaped like an arc or sloped trellis. The structures are generally used in combination with raised beds to minimize the risk of flooding and waterlogging. They are mostly employed for the production of sensitive crops such as tomatoes.

Rain shelter was initiated in ARDC, Samtenling, to grow tomatoes. Samtenling areas like most districts in Southern Bhutan receive very high rainfall in summer because of which crops such as tomatoes become highly susceptible to cracking and diseases incurring huge losses.

Figure 4. Rain-shelter technology in Tomato cultivation

Rain shelter is a knowledge and weather smart technology. It protects crops from rain damage and regulates humidity and temperature with its open side walls thereby reducing the incidences of fruit cracking and fungal and bacterial diseases. In Bhutan, it has been found to be effective to grow tomatoes in high-rainfall areas. An on-station observation in ARDC-Samtenling found rain shelters to reduce the disease incidence in tomatoes by almost 75%.

This technology holds huge potential and is ideal for small-scale farming. The structures are comparatively cheaper and easier to build. Currently, in Bhutan, rain shelters are used in research centers and are adopted by some farmers for the cultivation of tomatoes. However, the technology is relatively new and is not widely adopted. Furthermore, the rain shelters may not be as durable as prefabricated greenhouses as they are mostly made using local materials.

4. Crop Rotation

Crop rotation is the practice of planting two or more crops sequentially in the same field. In Bhutan, the rotation of crops such as paddy, vegetables, potatoes, and maize has long been in practice.


Figure 5. Paddy Field (L) and Wheatfield (R)

Crop rotation falls under the category of knowledge and nutrient-smart practice as it makes optimum use of information and resources available. The advantages of crop rotation are soil health improvement, reduced disease, insect and weed incidences, and crop diversification thereby increasing crop yield, diversifying and enhancing income, and improving climate resilience.

Crop rotation can be practiced in all agroecological zones. In Bhutan, the most common crop rotation practices are rice-wheat, vegetable-rice, maize-barley, maize-legumes, and potato-mustard. An estimated 60% of the wheat in Bhutan is grown after rice. A variety of vegetables like chili, beans, tomatoes, and peas are grown in paddy fields in the west and west central Bhutan. Growing legumes in rotation with maize is an established practice in the drylands under dry and humid subtropical agroecological zones. Similarly, rotation of potato and mustard is very popular in high altitude potato growing communities of Bumthang, Haa, Chukha, and Paro districts.

The technology is economically viable and can be practiced by smallholders and commercial growers alike. Given that the weeding is mostly undertaken by women in Bhutan, the technology benefits women farmers by reducing the workload of weeding. Crop rotation requires proper planning, however. Different crops have different requirements (soil type, topography, climate, nutrition, and irrigation) and management practices. If crop rotation is not planned or implemented properly, it can lead to imbalances in the soil nutrient composition and the build-up of pathogens. Therefore, good technical know-how in the choice of crops, cropping sequencing, and cultivation techniques is important.

5. Arecanut-based Multi-tier Cropping System

Multi-tier cropping is a practice of growing crops of different heights simultaneously in the same field. In Bhutan, the Arecanut-based multi-tier cropping system with coffee-banana-*Arachis pintoi* was initiated at ARDC, Samtenling in 2007. Arecanut-based cropping is a self-sustaining farming system, wherein resources such as solar energy, water, and nutrients can be efficiently used (Chandrashekhar & Bhattacharjee, 2018). This cropping system is a boon to small and marginal farmers of Bhutan where the average land holding is three acres per household (Katwal, 2013).

Figure 6. Arecanut-based multi-tier cropping system

Multi-storied cropping systems fall under the category of nutrient-smart and weather-smart technology. This cropping system has many environmental, social, and economic benefits. It ensures greater crop diversity and effective use of limited resources thus enhancing resilience, yield, and income (Nair & Verghese, 1976). The on-station data from ARDC Samtenling shows that in the 11^{th} year of the arecanut plantation, the benefit-cost ratio was 1.77:1 indicating a long-term economic benefit.

Arecanut-based multi-tier cropping systems are suitable in subtropical and tropical regions. In Bhutan, major arecanut-growing districts are Sarpang, Samtse, Dagana, and Samdrup Jongkhar. At present, the Bhutanese areca nut industry is largely based on a mono-cropping system with low returns from a unit area. Moreover, the crop is highly vulnerable to market price fluctuation, pests, diseases, and other natural calamities. Therefore, areca nut-based multi-tier cropping systems have significant potential.

6. Ultra-High-Density Fruits Plantation in Mango and Apple

Ultra-high-density plantation (UHDP) in fruit crops is a proven technology worldwide as one of the sustainable and climate-smart agriculture technologies. It has the potential to yield 200% more than the traditional method (Singh, et.al, 2017). The technology has the scope to utilize all the resources efficiently and as a result, increase the production per unit area. The UHDP was introduced at the National Centre for Organic Agriculture (NCOA) Yusipang in 2015 and ARDC Samtenling in 2016 in apple and mango respectively.

Figure 7. High-Density Apple Plantation (L) and High-Density Mango Plantation (R)

UHDP can accommodate 444 plants in an acre with plant-to-plant and row-to-row spacing of 3m x 3m which is four times more than conventional planting. The primary objective of UHDP is to obtain optimum production per unit area through the utilization of vertical and horizontal space with improved management practices. Thus, the technology is weather and nutrient smart technology. However, the identification of suitable fruit crops for UHDP is crucial to harness the optimum benefits of the technology. Thus, crops like mango, apple, citrus, banana, and pineapple are feasible by assessing the agroecological zones and geographical locations. Although the technology has immense benefits for marginal farmers, it has limitations because the farmers should have good knowledge of this production technology such as pruning, training, pests, and disease.

In Bhutan, the UHDP approach of the cropping system will be a boon to small and marginal farmers of Bhutan as each household has an average land holding of three acres (Katwal, 2013) and they need to extract maximum benefits from their limited land with increased yield and quality. It will lower the cost of production as a result of reduced labour requirements. It will also enable farm mechanization of fruit crop production and facilitate efficient use of fertilizers, water, and solar radiation (Rangare, n.d). As a result, the technology is women-friendly by nature once the initial establishment is done.

It can be implemented in districts where apple, lime, and lemons, arecanut, mango, banana, and guava are dominantly grown. It is applicable in districts like Paro, Thimphu, and Haa where apple is the predominant crop, and similarly, Samtse, Sarpang, Chhukha, Samdrup Jongkhar, Tsirang, Pema Gatshel, and Dagana where mango, citrus (lime and lemons), arecanut, banana, and guava are popularly grown.

7. Protected Cultivation

Protected cultivation is a practice of growing crops under controlled and regulated environments–enabling farmers to cultivate around the year. Essentially, protected cultivation entails modification of temperature, light, and humidity as per the requirements of plants.

The protected cultivation includes cultivation in mega greenhouses, polyhouses, and passive greenhouses. Mega greenhouses are large greenhouses that have ventilation at the top and side so that during the summer it can be open to keep the inside temperature cool and in winter the ventilation can be closed to keep the inside temperature warm. The poly house is a simple plastic house to protect crops from bad weather. The improved passive greenhouse has a double layering of greenhouse cover with air blown in between the layers and a stone wall (painted black color) placed on the north side of the plastic house. The air blown provides additional insulation. The stone wall painted with black color absorbs enough solar radiation during the day and releases heat slowly at night inside the greenhouse. The double-layer passive greenhouse with warm air blown inside double-layer plastic and black painted stone wall can retain much heat for the plant during the cold weather. This technology was introduced by the Agriculture Machinery and Technology Centre (AMTC).

Figure 8. Mega Greenhouse Structure

This technology saves crops from cold weather conditions in winter, heat in summer, and rain in monsoon seasons. Hence this technology is a weather-smart technology. Cultivation of vegetables under protected cultivation increases crop yield and fetches attractive prices –through off-season crop production–and helps to address the impacts of climate change. The incidence of pests and diseases is also reduced under protected cultivation. Furthermore, the technology has the potential to encourage and attract youth entrepreneurs in modern agriculture farming.

The protected cultivation is suitable for growing all types of vegetables. However, it is not effective in high-altitude areas where in winter the temperature is extremely low. Moreover, protected cultivation involves high establishment and maintenance costs.

8. Drum Seeder

Drum seeder is manually operated low-cost simple equipment for sowing paddy seeds. Direct seeding is generally followed in irrigated and wet fields. The seeds are sown through a drum seeder by using sprouted seed which is incubated and germinated to a height of 1mm to 2mm. Drum seeder technology has been introduced in Bhutan by the Agriculture Machinery and Technology Centre (AMTC).

Figure 9. Using Drum Seeder in the field

The drum seeder technology avoids nursery raising and transplantation as a result 58.15% of women's labour is saved. The technology does not use fuel and soil tillage is less. Hence this technology is climate-smart agriculture technology. The technology is simple, cheap, and portable that even women can easily operate and small-scale farmers can afford it. Drum seeder is disseminated in warm areas however, the trails in the colder regions are ongoing. The seeder is more suitable for medium-sized paddy seeds like Bhur Kambja 1. The technology was comprehensively tested in various fields in the past and received positive feedback from key farmers. Since then, the center has expanded this technology in warm areas of Sarpang, Chukha, and Samtse districts.

With support from the Food Security and Agriculture Productivity Project - FSAPP, 31 households in Samtse and Sarpang have adopted the drum seeding technology over the last three years. So far, close to 32 acres of wetland every year have been brought under cultivation using the technology in these two districts. It has been reported that paddy cultivation using a drum seeder not only provides a comparatively higher yield (1.4MT/acre) as compared to transplanted rice (1.3MT/acre) but also reduces the cost of cultivation by almost 53%. However, this technology needs assured irrigation, sometimes heavy rain, and damage by birds have been observed at the sowing time.

9. Sustainable Water Management

The water pump is a portable device used for pumping a huge amount of water from one place to another for housing, farming, municipal, and manufacturing applications. The electric water pump reduces the cost of water pumping, allowing farmers to cultivate water-intense summer crops, improving land use, and increasing the use of clean energy.

The agriculture water pump is the most effective machine for irrigation purposes. They play a fundamental part in agriculture as they pump water from the source to the agricultural fields. Electric pumps can be used for many types of irrigation, such as drip, sprinkler, and hosepipe. The electric water pump is the technology to alleviate the heat stress/drought effect caused due to climate change.

There are various types and different-capacity water pumps available in the market. The user can select based on the requirement and can be installed where it is safe from flood and electricity available. Due to an extreme shortage of irrigation water, farmers have started using water pumps for irrigation of paddy and vegetable cultivation. The farmers also started using smart irrigation such as sprinklers and hydroponics where the water pump is mostly used.

Most small-scale farmers who own smart irrigation in greenhouses have started using a small electric water pump. This is small, efficient, cheap, easy to operate, and gender friendly. The electric water pump can solve irrigation issues, increase productivity, and reduce fallow land. It can be installed easily in any facility such as hydroponic, sprinklers, and other smart agriculture technology. With the increasing adoption of hydroponics, sprinklers, and drying of water sources, the use of water pumps has been increasing. However, the installation of large electric water pumps is expensive for small and individual farmers.

10. Sustainable Land Management

Bhutan is a mountainous country, and farmlands are largely on the mountain slope. While more than 70% of the country's agricultural land is on steep slopes, 31% of it is on a gradient above 50% (Katwal, 2013; DoA, 2017b). As a result, agricultural lands are prone to land degradation, particularly landslides and erosion.

Following the devastating flash flood in 2004 that affected the lives and livelihoods of farmers in six eastern districts, the Sustainable Land Management Project (SLMP) was launched in 2006 to combat land degradation. The project, funded by the World Bank, introduced and promoted SLM technologies such as contour bunding, check dams, and terracing. These SLM technologies are further promoted as part of Agriculture Land Development in the country. The National Soil Service Centre (NSSC) under the Department of Agriculture is the lead agency to promote SLM technologies in the country.

Figure 10. Land Terracing (L) and Stone Bunding (R)

Climate change is expected to accelerate soil erosion due to the increased frequency and intensity of rainfall events (Nearing et. al., 2004). Soil erosion is one of the major causes of soil degradation that affects crop production due to the loss of fertile topsoil. In Bhutan, topsoil removal by soil erosion ranges from 3 – 21 t ha^{-1} annually (DoA, 2017a). Degraded soil has poor vegetation due to which carbon sequestration is reduced, thus contributing to climate change.

SLM technologies help to build farming communities' resilience to climate change. The technologies are intended to minimize soil erosion, improve soil water storage, and retain nutrients to maintain crop production. NSSC (2009) reported that surface erosion was reduced by up to 46% by planting hedgerows in dryland. Plantation of hedgerows also has added benefits in terms of carbon sequestration, thus mitigating climate change.

Despite many benefits, there are also some drawbacks of the technologies. SLM technologies are in general labor intensive and it is capital-intensive with no immediate returns.

The technologies comprise a package of soil and water conservation practices. Different SLM technologies are suitable for different topography and agro-ecosystems. For example, terracing is commonly applied in dryland conditions while contour bunding and hedgerow plantations are carried out mostly in high-gradient farmlands.

SLM technologies provide long-term socio-economic and environmental benefits to the communities, and as a result, there is a high acceptability of the technologies by the farmers in general. BTFEC (2019) highlighted that close to 7,700 acres of vulnerable land were restored using SLM technologies in three SLM pilot districts namely Tashigang, Zhemgang, and Chukha. However, the adoption of SLM technologies and their sustainability is affected by myriads of factors, one being how imminent and severe the impact of climate change is on the farmers. Smallholder and marginal farmers are more vulnerable to climate change. SLM technologies have the potential to benefit smallholder farmers by maintaining crop productivity in their limited land. Likewise, the technologies also create opportunities for farm mechanization and help reduce drudgery for farmers including women in agriculture.

Sustainable Land Management in Salamjee village in Dagana district in west central Bhutan is a success story of SLM technologies. Salamjee village situated on a steep mountain slope was affected by landslide and soil erosion due to which the livelihood of the entire community was at risk. The Government's proposal to relocate the village was rejected by the community, so the sustainable land management project was launched with funding from the GEF Small Grants Programme in 2007. The project intervention has reclaimed 200 hectares of degraded land including forest areas and converted the village of 18 households into a vibrant farming community. Farmers now cultivate vegetables and fruits from this reclaimed land, not only for household consumption but also for sale in the market. A farmer group has been formed by these households, and are making voluntary monetary contributions of Nu.200 half yearly to the group for funding the SLM activities in the village. In this manner, SLM activities are being carried out regularly in the village.

SLM technologies are costly for small and marginal farmers practicing subsistence farming. The labor-intensive nature of the technologies is also a challenge, especially in the wake of labor shortage and feminization of agriculture in the country. There is already a cost-sharing mechanism to support farmers with the technology (DoA, 2017a). However, it may be reviewed and improved to make the technologies affordable to farmers. Providing funding support, technical guidance, and awareness programs, would create favorable conditions for the uptake of the technologies.

11. Site-Specific Nutrient Management

Site-specific nutrient management (SSNM) is a nutrient management strategy designed to improve nutrient use efficiency by carefully considering the spatial and temporal variation of indigenous soil fertility in the field. The concept, introduced in the 1990s was first used for developing field-specific fertilizer recommendations in rice in Asia (Chivenge et. al., 2022). It is now one of the components of precision agriculture. In Bhutan, SSNM technology is still new and is now being promoted in a few selected districts namely Haa and Chukha by the National Soil Service Centre with support from the Agriculture Productivity Project (FSAPP) funded by the World Bank.

Figure 11. Site specific nutrient management in Potato

Chemical fertilizers are one of the sources of GHG namely N_2O. Soil exhibits variability across the field in its inherent fertility, and blanket fertilizer recommendation as common practice leads to an oversupply of nutrients in some parts while there is an undersupply in certain places. Such a situation, on the one hand, increases the risk of environmental damages including GHG emission from excess fertilization while on the other hand, lowers the yield due to nutrient deficiencies. Thus, SSNM has the potential to mitigate climate change and environmental contamination by reducing the wastage of nutrients and minimizing associated costs. Additionally, it will help to realize the full potential of crop yield by supplying the required quantities of nutrients.

In Bhutan, although the use of chemical fertilizers is low at present, there is an increasing trend with a growth trajectory into the future. This is a growing cause for concern over the environmental damages from the use of chemical fertilizers. In this respect, SSNM provides hope and confidence in the safe usage of chemical fertilizers, which are essential for enhancing crop productivity. SSNM is data-driven and requires geoinformatics such as remote sensing (RS), geographic information system (GIS), and Global Positioning System (GPS) (Verma et al., 2020). These required a specialized set of skills, and equipment, which may prove to be the downside of SSNM.

SSNM entails dividing the field into a zone of homogeneous field productive units (HFPU) and application of varying amounts of nutrients based on the level of inherent nutrient contents. It could also be applied in any agroecosystem and for any crops based on the yield targets. However, SSNM alone may not be adequate to see the expected result.

Integrating SLM technologies with SSNM may make it more effective and maximize the benefits by combining their effects.

SSNM is new in the country and is being piloted in a few selected districts. NSSC is assessing soil fertility to develop nutrient maps at the district level. This would serve as a decision support tool for the farmers to follow site-specific nutrient management. Given the increasing fertilizer costs and inconsistent supply which are already affecting farmers, there would be high acceptability of the SSNM tool by the farmers. Smallholder and marginal farmers rely mostly on organic manure for nutrient supply. Farmyard manure preparation and application are labor intensive and are carried out mostly by women. With the SSNM, it will encourage farmers to use chemical fertilizers for better crop productivity, and also directly benefit women farmers. SSNM will serve as a decision support tool to guide farmers for balanced and efficient nutrient management.

SSNM is likely to offer cost benefits to the farmers in nutrient management practices. The crop yield is also expected to be higher compared to conventional practices due to improved nutrient use efficiency. SSNM should be promoted at a national scale on all major crops. This should be followed by advocacy and education on the interpretation and use of SSNM as a decision-making tool. SSNM will recommend the use of chemical fertilizers, so the availability of these chemicals will be critical in scaling up the technologies.

12. Nano-Fertilizers

Nano-fertilizers are ultra-small sized nutrient particles whose size ranges from 1-100 nm and are encapsulated with materials such as metal oxide, ceramic, magnetic materials, lipids, polymer, and emulsions for controlled release of nutrients (Mejias et al., 2021). National Soil Service Centre is currently conducting multi-location on-station and on-farm trials of Nano urea (Liquid) on rice, maize, and potato to evaluate efficacy in the local environment.

Figure 12. Nano fertilizers application in Potato

Chemical fertilizer is considered one of the driving forces for the green revolution worldwide. However, its excessive use has caused environmental concerns and is found to be a major source of nitrous oxide emission (Smith et al., 1999; Snyder et al., 2014; Wang et al., 2021).

Nano-fertilizers have the potential to mitigate climate change. Its “smart delivery system” through leaf stomata ensures higher uptake by crops and minimizes losses into the environment. Furthermore, given its higher nutrient use efficiency compared to conventional granular fertilizers, crop productivity is also higher. Overall, the use of fertilizers will be minimized, providing economic benefits to the farmers.

Nano-fertilizer is relatively new, and not popular among Bhutanese farmers, which is one of the limitations. As of now, P and K nano-fertilizers are not widely available, so farmers may have to continue to rely on conventional fertilizers. However, during the on-field demonstration, farmers showed great interest in nano-fertilizers, indicating the likeliness of high acceptability by them. Their strong interest was based not only on the cost benefits but also on ease of handling in terms of transportation and storage. The use of equipment such as sprayers may also be a barrier in the application of nano-fertilizers. Nano-fertilizers are best suited for cereals, and vegetables cultivated in the country. However, it may prove to be difficult to use in fruit crops such as citrus and apple, having to spray on the tree canopy. Foliar spraying of nano-fertilizer is also not recommended in rain, so it may not be suitable for summer crops whose growing season falls in the monsoon season.

Since nano-fertilizers are new and are undergoing trial in the country, there is no success story on it. However, it is found to be cost-effective. The quantities required and rate of nano-fertilizers are much lower than the commercial chemical fertilizers. The recommendation for nano-fertilizers is 250 ml per acre, and the total quantity required for two sprays is 500 ml, which costs around Nu. 250 (1USD = Nu.76.9). Given its comparative cost-benefit and other associated benefits, nano-fertilizers would be suitable for small and marginal farmers to ensure that their limited landholding is efficiently used. In the wake of agricultural feminization in the country, nano-fertilizers, which are gender friendly will benefit women farmers.

Awareness and advocacy on the use and benefits of nano-fertilizers may be crucial in popularizing the fertilizers. Since its foliar application requires equipment such as a sprayer, support in terms of supply of such equipment may contribute to scaling up the technology. Additionally, to make all-season fertilizers, a study on the use of stickers along with the nano-fertilizers may be necessary.

13. Integrated Pest Management (IPM)

Integrated pest management (IPM) is the environmental-based procedure of long-term prevention of pest or their damage to crops through the combination of various methods such as biological methods, cultural methods, use of resistant varieties, and alteration of environmental conditions. In this technology, only a specific pest is targeted and the use of less toxic and environment-friendly ingredients are focused on reducing detrimental effects on the environment and biodiversity while synthetic pesticide is used as the last resort for pest management.

The IPM technology combines the following methods:

- **Cultural methods**: The IPM emphasizes on use of various cultural methods such as the use of resistant varieties, alteration of environment, shifting of sowing date, and modifying planting densities. For instance, the cultivation of chili on the raised bed, adopting wider spacing between the plants, and use of furrow irrigation are promoted to prevent the spread of *Phytophthora capsici*. Similarly, chili blight does not cause serious damage to chili in certain parts of Punakha as chili plants are uprooted to transplant right before the commencement of monsoon.

- **Mechanical and physical methods**: Various mechanical and physical methods focused on managing pests below the economic threshold level. For example, different types of traps (Table 2) are used to monitor and manage the population of pests in the field. Additionally, solarization of soil and heat treatment of seeds is focused on the prevention of soil and seed-borne diseases.

Table 2. List of Traps for Pests available at the National Plant Protection Centre

SN	**Biochemical**	**Target pest**
1	Pheromone	Mango Fruit fly, Rice ear- cutting caterpillar, Fall armyworm, Red palm weevil, Chilli pod borer, Potato tuber moth, Diamondback moth
2	Azadirachtin (Neem oil)	Aphids, bugs, whiteflies, mites etc.
3	Protein hydrolysate	Citrus fruit fly

- **Biological method**: Various natural enemies and biopesticides as mentioned in the biopesticide section are used for the prevention and management of pests and diseases in the crops. These biocontrol agents are used before using synthetic pesticides.
- **Chemical method**: Pests are managed using synthetic pesticides as a last resort only after implementing all other methods. Moreover, the synthetic pesticides available at NPPC are less hazardous which falls below class II of WHO's hazard classification of pesticide.

The use of biopesticide, cultural methods, and mechanical methods has a positive effect on the environment and biodiversity reducing exposure of nature to synthetic pesticides, the IPM technology is carbon, biodiversity, weather, and water smart technology.

The components of IPM are applicable to any cropping system and it can be designed for any farming system. The programs can be designed for any specific area or region based on the presence of pests and diseases in the field. The cultural and mechanical methods also depend on the type of soil and surrounding environment. As biopesticides, especially microbial biopesticides are target-specific, their efficacy in pest management is also driven by environmental conditions of the area. Therefore, microbial biopesticides need to be selected based on agroecological zones.

The IPM program not only effectively manages target pests but also enhances the growth and productivity of crops through various intercultural interventions. The IPM technology avoids the use of synthetic pesticides while protecting crops from pests and diseases using cultural and biological methods. Due to the positive effect of IPM on plant, environment, and human health, the technology is widely adopted and provides a reliable source of income to farmers.

The main focus of IPM technology is to prevent pests and diseases in the field through safer methods such as cultural, mechanical, and biological methods before opting for synthetic pesticide application. There is a huge benefit in reducing the cost of input and also provides a sustainable source of income through the production of safer products with less pesticidal contamination. The technology, when designed specifically for the area, effectively manages target pests, reduces the cost of inputs, provides a sustainable source of income, and improves farm resilience to climate change through positive effects on biodiversity and the environment. Thus, the technology can be scaled up to any farming system. Additionally, various government policies have been encouraging to reduce use of synthetic inputs in farming systems.

14. Bioacoustics system

Bio-acoustic scarer is an electronic, digitized recording of a distressed animal that replays at random intervals over time. It is designed to be heard by the animals and hence to create a sense of danger, alarm, and perceived threat to the wildlife to the extent that animals flee the immediate vicinity of the threat. The secret to the bio-acoustic distress call system's effectiveness lies in the undetectability of the source of the predator. Because the wildlife is unable to locate the source of the call, it will not be able to get "eyes-on" to its enemy/predator. This creates a sense of anxiety. Hence even the boldest wildlife flees the area as they become acutely unnerved by the system not presenting a visible threat. It is a knowledge-smart technology.

Most Bhutanese farmers spend sleepless nights guarding their farms from wild animals. As the guarding of the farms is laborious, more than 6,400 km of electric fencing were installed protecting 61,000 acres of land from wild animals till 2021. Agriculture Machinery and Technology Centre (AMTC) designed and developed Bioacoustics automatic animal-repellent technology which works on the predator-prey concept. It is the Internet of Things (IoT) based technology that would discourage wildlife intruders from entering the farmers' fields with different predator sounds, movement of scarecrows with high beam LED light, and simultaneously notify the farmer on their phones through sensors. The traditional methodologies can be integrated with the latest technologies like the IoT to enable various applications in the Digital Agriculture Domain. Changing the sound recorded in the bioacoustics system can be used to prevent the intrusion of almost all the common vertebrate pests such as monkeys, wild boar, sambar, and deer. The system is also not restricted to a single season or cropping pattern. It can be used to prevent the invasion of wildlife in any cropping area from vegetable gardens to orchards throughout the year.

Bioacoustics systems are less laborious, simple, and cheaper technology compared to electric fencing. It can reduce the time needed to protect the fields, freeing up valuable time that can be devoted to other farm tasks and household responsibilities. Thus, the technology is smallholder and women-friendly.

15. ePest Surveillance System

The ePest surveillance system uses an Android-based phone that has a combination of various cutting-edge technologies (GPS/GPRS/GSM) for real-time geo-referenced data collection. It is connected to a central server that allows rapid data entry, collation, and analysis and makes the reports available in real-time to the participating blocks, districts, and research centres. Any desired combination of qualitative and quantitative outputs can be generated that may be used to develop strategic pest management plans. As this system can gather and store information for any given time, it will allow us to study the trend of pests' occurrence with reference to contributing factors such as climate change and changing crop production systems. The trend in pest occurrence under variable climatic conditions will enable us to develop pest Forecasting and Early Warning Systems.

The objectives of a pest surveillance system are to monitor the presence of existing and new pest species and also to assess pest population and its damage at different growth stages of crops. Over the period data generated through the system would enable us to study the influence of weather parameters on pests and their effects. It would help to assess natural enemies and their influence on pests. This knowledge of smart technology would help in mitigating the effect of climate change on pest management.

The system can be used by all literate individuals at anytime and anywhere to report, record, and generate information on pests and diseases. Moreover, the user can also use the system to record and report the pests even from remote places without an internet connection. The report gets auto-synced as and when the user gains an internet connection. The information on the present prevalence of pests and diseases in the area and its likelihood of an outbreak in the future will be useful to farmers in making appropriate decisions for management. However, illiterate farmers may not be able to directly reap the benefit of this system. For that, the report and the information generated from this system should be disseminated to farmers through agriculture extension services centres and also through reliable media outlets.

16. Biopesticides

Biopesticides are any non-toxic pesticide derived from natural sources such as microorganisms, plants, animals, and certain minerals. The biopesticides available at NPPC are broadly classified into two categories:

- **Microbial biopesticides**: These are biopesticides that contain microorganisms such as bacteria, fungi, viruses, and nematodes as primary active ingredients for the protection of crops against pests and pathogens. These microorganisms use different mechanisms and modes of action against the pest and are known to be target-specific. Currently, the NPPC has isolated a beneficial fungus, *Trichoderma* spp. from the native soils which can be used against a wide range of soil-borne and foliar pathogens of crops including *Phytophthora* spp., *Pythium* spp., *Anthracnose* spp., *Alternaria* spp., *Rhizoctonia* spp., *Cercospora* spp., etc. Similarly, NPPC has also isolated native entomopathogenic fungus, Nomuraea spp. which is a potential natural enemy of chilli cutworm (A*grotis segetum*), chilli pod borer (*Helicoverpa armigera*), fall armyworm (*Spodoptera frugiperda*) and other pests.
- **Biochemical pesticides**: These are biopesticides derived from natural substances such as plants and minerals that alter the biological and physiological mechanisms of pests and pathogens. It includes natural substances that interfere with mating (sex pheromones) and attract pests to traps (lures and taps). Some of the biochemicals available at NPPC are listed in Table 3.

Table 3. List of biochemicals available at NPPC

SN	**Traps**	**Target pest**
1	Light trap	hoppers (*Nephotettix nigropictus, Nilaparvata lugens*), yellow stem borer (*Scirpophaga incertulas*)
2	Sticky trap	hopper (*Nephotettix* spp., *Nilaparvata lugens*, *Recilia dorsalis, Sogatella furcifera*)
3	Coco trap	Weevil, beetles
4	Mcphail trap	Flies and Wasps
5	Fero-TR trap (funnel trap)	Mango Fruit fly, Rice ear- cutting caterpillar, Fall armyworm, Chili pod borer, Potato tuber moth, Diamondback moth

Biopesticide is less toxic and target-specific. So, the biopesticide affects only target pests and no other organisms such as birds and wild environment. Biopesticides are less harmful and decompose quickly, lowering environmental pollution causing less harm to micro-biodiversity and ecosystem. The use of biopesticide while enhancing a healthier ecosystem also reduces carbon dioxide equivalents (CO_2e) emission, the technology is carbon and ecosystem smart technology. Whereas, the use of synthetic pesticide results in high emission of CO_2e during production, transportation and application. For instance, use of synthetic pesticide in the USA alone is responsible for annual emission of as high as 40 million kg CO_2e (Heeb *et al*, 2019).

The above list of biopesticides can be used to manage a wide range of pests and diseases of crops. These biopesticides have huge potential to not only manage pests and diseases but also to enhance productivity and can be used to produce healthier yields in all farming systems. Thus, it is suitable for the management of pests of both field and horticultural crops. These organic products fetch comparatively higher prices in the market while the growers/farmers directly contribute to global environment conservation. As such, the technology is the preferred option for the management of pests and diseases among the farmers of Bhutan in all agro ecological zones.

The microbial and biochemical biopesticides are available in both liquid and powder formulations. As such, it is relatively easier and safer to use in the field. Moreover, the microbial biopesticides can be also mass multiplied by individual farmers which results in reduced cost of the inputs and is suitable for smallholder farmers as well. The use of biopesticides eliminates exposure of farmers and the environment to toxic hazardous synthetic pesticides. This can help the farmer in reducing external costs such as the cost of human health. Further, the use of biopesticide has a positive effect on biodiversity which enhances the resilience of the farming system. Use of biopesticides has huge potential for scaling up as it has a positive effect on biodiversity, reduction of input cost, and higher market value of the produce. However, the adaptation is hindered by target specificity, slow effect, and unavailability of wider options for biopesticides.

17. Smart Electric Fencing

In 2013, to reduce the wildlife depredation on crops, electric fencing fabricated by Agriculture Research and Development Centre-Wengkhar were installed (Penjor *et al*, 2014). The electric fence was fabricated using local materials such as galvanized iron (GI) wire, wooden post/post made of recycled waste/metallic post, and HDPE insulator and can also be operated using solar energy. It produces electric shocks to repel animals when they come in contact with GI wire and creates a psychological barrier, preventing the invasion of animals into the field.

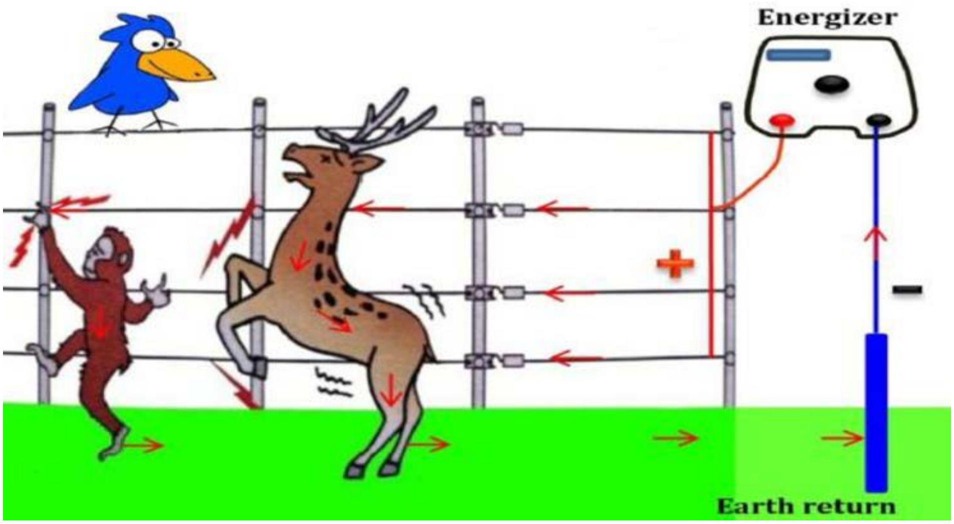

Figure 13. Smart Electric Fencing

Since solar energy powered by an energizer is the main source of energy for the electric fences, it is an energy-smart technology. The use of posts made out of recycled waste instead of wooden posts reduces the reliance on forests for wooden posts. It is also more durable and reduces maintenance costs incurred in replacing damaged wooden posts. Similarly, Portal Electric Fence (PEF) uses mild steel (MS) flat posts which reduces wooden post requirements by 99%. The durability of MS flat post is more than 25 years. Thus, the technology is also a carbon smart technology when wooden posts are replaced by durable MS flat posts made of recycled waste. It is also a climate-smart technology since the technology provides efficient adaptation to wildlife invasion and mitigation of afforestation.

The electric fencing system can be used against various wildlife by adjusting the strength of energy and the number of fencing wires (GI). The higher power of 12 volts can be used against huge wildlife such as elephants in southern Bhutan and the fence with the closer and higher number of GI wires can be used against smaller animals. The system is also not restricted to a single season or cropping pattern. The system can be used to prevent the invasion of wildlife in any cropping area from vegetable gardens to orchards throughout the year.

Until 2021, more than 6,400 km of electric fencing were installed protecting 38,000 and 23,000 acres of dryland and wetland respectively from wild animals. Moreover, the fence can be installed by a group of farmers around the community or a field by a single farmer. As such, it is a highly adapted technology among the farmers with HWC conflict. Compared to conventional electric fencing, PEF requires limited effort, saves time and labor in installation, and is equally effective. The use of easily stretchable poly wire and

MS flat posts (less than 2 kg each) in PEF makes it very friendly to and popular among women and smallholder farmers.

The impact assessment of the electric fence conducted by NPPC in 17 districts found that the crop loss to wildlife has reduced more than 23% which is a huge reduction and immense benefit to the farmers. The use of wooden posts, quick rotting of wooden posts, rusting of GI wire, and intensive labour requirements are some of the key challenges of conventional electric fencing but the PEF overcomes all these challenges. Thus, PEF has a huge potential for scaling up.

18. Google Assistance in Agriculture

Google Assistance is a software application, available on mobile phones and is developed by Google. It functions based on artificial intelligence in a two-way conversation. The Google Assistant can respond based on the queries from the users' Google Account. Google Assistant model in Agriculture was first operated during the 7th Royal Bhutan Flower Exhibition (RBFE), 2022 at Gyelpozhing, Mongar District. This technology needs more research as it is just initiated. Prior to real usage, feeding in the need-based information must be done. For example, to control the climate inside the protected cultivation based on the crop requirement, the information related to the crop like temperature, humidity/moisture (soil & air), and light must be fed into the operation system. Google's smart speaker is integrated with a Google Assistant account. Similarly, the Google Assistant based on the command helps to switch on and off the ceiling and exhaust fans, lights, pumps, and other automation parts. The basic features of the technology include Google Assistant, Speaker, and feed-in information. The automation part is also integrated into the operation system.

The technology falls under the knowledge smart category as it is used in integration with the Internet of Things (IoT). The operation system is even integrated with the automation system and made effective for use. However, the initial technology setup and installation needs advanced skills and knowledge. It is feasible and suitable in all locations. Currently, it is focused on operating in protected cultivation areas. However, it can be implemented in open areas. The technology is new in the Bhutanese context. However, its benefits of integrating with other systems can add to its advantage. Thus, adaptation of the technology may not be a big issue in Bhutan. Its use and application must be studied ahead. The use of technology is suitable due to its low cost. All levels of farmers including women can operate the technology because of its simplicity.

This technology is demonstrated to bring easy and cheap automation solutions in agriculture. It can be used by all young farmers, literate farmers, and even differently-abled people who can avail of the technology. A few enabling factors of the technology are easy to operate, low cost, and applicable in all locations. However, the initial setup of the technology needs a skilled person.

19. Shoot tip Grafting In-Vitro

Citrus, belonging to the Rutaceae family is one of the major cash crops for Bhutanese farmers but with the prevailing citrus diseases such as citrus greening, the yields have been reduced significantly. For instance, in the year 2010, 52,621 MT were produced and in 2020, only 25,560 MT were produced (NSB, 2020). To revive the citrus industry in the country, ARDC Wengkhar initiated a research trial on shoot tip grafting to produce disease-free planting materials, free from Huanglongbing (HLB) and Citrus Tristeza Virus (CTV). The shoot tip grafting technique is proven to be the most reliable method to recover pathogen free citrus seedlings from infected parental sources (Deshmukh S. Snehal, Gahukar J. S. & Muske N. D., 2021). The features of the Shoot Tip Grafting (STG) in-vitro consist of grafting a small shoot tip of 0.1 to 0.3 mm onto a young seedling rootstock growing in-vitro under aseptic conditions. The procedures for shoot tip grafting involve root stock preparation, scion preparation, grafting under a microscope, and double or re-grafting of STG to bigger rootstock.

The technology can be knowledge-smart as expertise and skills are used for the development of the technology. It requires laboratory facilities and must be done in a closed environment as the technology aims to produce disease-free planting materials. Its adaptability rate in the farmer's field can be low due to the need for an expert and skilled person. However, the technology can be taken up by educated youth farmers. The technology can be taken up by smallholder, but educated and skilled farmers in a confined area (laboratory). It is appropriate for women as the technology does not demand physical strength.

The technology is currently in the research station. With the advancement and development, educated youths can benefit from taking up the technology and developing it into an enterprise. However, the main challenge of the technology can be cost-intensive as there is a need for laboratory facilities and require skilled manpower.

20. Heat Tolerant Maize

Maize is a widely grown cereal in the country. It is a major source of household income and food security especially for the poor farmers. It is stipulated that in the future heat stress in crop production will be one of the major constraints in Southeast Asia. To combat the negative impact of abiotic stress, Bhutan joined Heat Tolerant Maize for Asia (HTMA) in 2014 to assess the germplasm and evaluate under our condition to prepare against any possible heat stress on maize in the future. The evaluation of germplasm in Bhutan started in 2015. The program was coordinated and initiated by ARDC Wengkhar. The centre carried out multiple trials both on the station and in farmer's fields. After evaluation for 3 years, ARDC Wengkhar successfully released a variety of HM-1.

Figure 14. Heat Tolerant Maize Var. HM-1

Heat Tolerant maize is a weather-smart technology as it is a heat-stress-resilient variety and gives a higher yield. HTM is grown in lower regions at an altitude ranging from 600-1600 masl. It requires a well-drained sandy loam soil with organic matter. The growing season is from February to June. Hybrid maize has seen successful adaptation and acceptance among Bhutanese farmers in the potential sites mainly for its high yield potentials of about 1800 to 2000 kgs/acre and adaptability. Hybrid maize matures earlier than the local variety and enables farmers in lower foothills to go for double cropping producing early *tengma* (maize flakes) and *kharang (maize groats)*.

Over the years, cultivation of heat-tolerant maize has increased significantly. With an initial start of 90.6 acres under cultivation, it has increased to 314 acres. The total production in 2020, was 445 MT from 487 households.

21. Automated/Smart Irrigation Technology (SIT)

The technology was developed by ARDC, Wengkhar, through ACIAR, EU-GCCA, and CARLEP-IFAD funds and was first developed and tested in the Research Centre in the fiscal year 2014-2015. The hardware controllers are based on open-source firmware and low-cost hardware platforms such as Raspberry PI, Arduino, ESP8266, and ESP32 Micro-controller unit (MCU) boards. The local weather data can be fed to these controllers through the Wunderground website, which controls the amount of water applied to the crop based on the weather parameters pre-set in the program by the users. Smartphones and personal computers can access the system through open-source software and mobile applications like Open Sprinkler. The system users can virtually control and even monitor the irrigation system from anywhere with the use of an internet facility through an Intuitive User Interface (UI). The technology has been tested and demonstrated in the following locations in Bhutan.

Table 4. Locations tested for smart irrigation technology

Place	Year of installation
ARDC, Wengkhar	2014-15
ARDSC, Lingmethang Khalangzi, Mongar	2019
Jangdung, Mongar	2017-18
Chimipang Agriculture Development Training Center (ADTC),	2019
Wangduephodrang Tashichhozong	2019
Garden Project	2019
National Seed Centre (NSC), Tyangtse	2019
Majathang Outreach area	2017-18
Drepong, Mongar	2020
Marpheng Youth Commercial Farm, Tgang	2019
Nabar village, Jarey, Lhuntse	2019
LUC Tsendung, Tyangtse	2019
RDTC, Zhemgang	2019
LUC, Nyamead, Ngatshang, Mongar	2020

It is found to be economical and has the potential to scale up in commercial farms for efficient irrigation and water conservation.

Figure 15. Smart Irrigation Technology

The technology will fall under water and knowledge smart due to its efficient and sustainable management of water resources in agriculture production. Commercial farmers have more benefits from using the technology. However, the user must be literate as one must know the operation through the mobile application. It has a high initial cost, about Nu. 0.38 million/acre for installation. It is suitable in all agroecological l zones. However, the cost of installation may vary depending on the location.

The adoption of this technology is in an increasing trend. Since the start of the technology, a total of three commercial youth farmers, three commercial farmers, other centres, and outreach sites in 14 different locations have been in use of the technology. Adaptation of the technology with reference to climate change is highly applicable. The technology will be easily taken up by the educated youth farmers and literate farmers.

Technology will not be cost-effective if installed by backyard farmers as the cost of installing the technology in an acre area is about Nu. 0.38 million. It must be focused on commercial use for its cost-effectiveness. The women going for commercial farming with this technology will get ample time for other household chores as nutrient supply and irrigation are automatic. The most enabling factor of the technology is the cost-effectiveness for commercial use. High initial cost and the requirement of literate people to operate are the challenges in the adoption of this technology.

22. Low-cost Bamboo Greenhouse

The greenhouse is a structure used for crop cultivation, and vegetable and fruit nursery purposes in a controlled condition. Among many types of greenhouse structures, low-cost bamboo greenhouse structure is one of the cheapest technologies promoted in the farmer's field. The technology can be adopted easily by farmers of different income levels. The size of the technology solely depends on the users. The technology was implemented in the field some years ago and is still in use as it is cost-effective. Almost all the regions in Bhutan have the technology in place.


Figure 16. Low-cost poly-house using bamboo frames

It is a weather-smart technology due to its diverse adaptability. This technology can be implemented in a wide range of climatic conditions depending on the needs of the user and crop types. It is specially used in higher regions to combat colds. This technology is widely accepted by the farmers as the implementation of the technology is an increasing trend.

Smallholder farmers are best suited for the technology as they can grow diverse crops in the limited land throughout the year thereby enhancing self-sufficiency. The technology can be lucrative for the smallholders. It is also women-friendly due to its easy management. The technology is affordable and does not require expertise for the construction. It is climate-resilient technology and eco-friendly. The resources are cheap and readily available. The enabling factors of the technology are cost-effective and require a small space for installation. This technology attempts for off-season crop production and early nursery seedling production. However, this technology is less durable compared to prefabricated greenhouse structures.

23. Heat Tolerant Vegetables

Cole crops including cabbage and cauliflower belong to the Cruciferae family which grows well in cooler temperatures. Most cabbage and cauliflower grown in the country are conventional varieties that grow well in cool seasons and do not tolerate high temperatures. In 2020, 7829.57 MT of cabbage and 2447.8 MT of cauliflower were produced in Bhutan during the cool season (Agriculture Statistics, 2020). To enhance year-round production, especially during the summer season, ARDC Wengkhar has introduced and evaluated heat-tolerant varieties of cabbage and cauliflower. Two heat-tolerant cabbage varieties viz Bengal King and Asha and cauliflower varieties viz White Express 50 and Pragati 40 were evaluated. These varieties can be produced in the summer season with marketable head weight.

Figure 17. Heat Tolerant cauliflower (L) and cabbage (R)

It is weather-smart technology that has the potential to produce off-season cabbage and cauliflower under high temperatures in the summer season which will enhance vegetable production in warmer areas unlike existing conventional varieties and contribute to increased vegetable production. Heat-tolerant Cabbage varieties Asha and Bengal King can be grown at the altitude range of 1800 - 2100 masl from May to July at 1400 -1800 masl from April to August and below 1400m from March to September. For heat-tolerant cauliflower varieties, White Express 50 and Pragati 40 can be grown at the altitude range of 1400 - 1800 masl from May to July and below 1400 masl from May to September.

The heat-tolerant cabbage and cauliflower varieties were evaluated at research centres and sub-centres in Khangma (2100 masl), Wengkhar (1650 masl), and Lingmithang (650 masl) and have shown tolerance to high temperatures and can be produced in peak summer season for low lying areas. The technology will enable cole crop production in warmer areas and contribute to increased vegetable production in the summer season which will benefit smallholder farmers residing in low areas.

As per the research evaluation, both heat-tolerant cabbage varieties Asha and Bengal King can be produced during the hot summer season. Asha variety has export potential due to its ideal size. The heat-tolerant cauliflower varieties like White Express 50 and Pragati 40, can be produced during peak summer season and both varieties will be suitable for export as they have small heads. Pragati 40 is more heat-tolerant than White Express 50 and therefore enables crop production even in summer for low-altitude areas. There is limited vegetable production in low areas during the summer season; hence it will enable vegetable production in low-lying areas during the off-season and has the potential to generate income. The main challenge in scaling up would be the availability of seeds since it has to be imported.

24. Spring Paddy

Rice is the main staple food in Bhutan and plays a vital role in the economy of our country. Realizing the importance of this commodity, Spring Paddy was mainly promoted to revert fallow wetlands to enhance household rice self-sufficiency and also to have more varietal choices for the farmers. ARDC Wengkhar in collaboration with ARDC Samtenling and Agriculture Extensions carried out an intensification of spring paddy with those potential communities that are vulnerable to climate change and in places with high poverty rates.

Figure 18. Nursery raising of spring paddy and in field

Spring paddy is a weather smart technology as it is an off-season crop which gives our farmers a provision for double cropping ensuring higher productivity and enhancing food self-sufficiency at a household level. The farmer becomes less dependent on the imported rice and also allows them to generate income from this off-season rice. Spring paddy is normally grown in sub-tropical regions at an altitude ranging from 650 - 1100 masl and the growing season is from February to July. The program has been successfully adopted by the farmers as it helps farmers achieve rice self-sufficiency at the household level and also creates varietal choices in the market for the consumers. It also helps large-scale farmers to generate income as it is off-season paddy.

It is suitable for smallholder farmers as it permits production twice a year. The Spring rice can enhance productivity and ensure food security at farm, community, and National levels. The cultivation practices have declined over the years due to labour shortages and low productivity. However, this program will help to revert the fallow land in the locality to cultivation and enhance self-sufficiency at a household level. To facilitate spring paddy cultivation, it is crucial to provide farmers with high-yielding and climate-resistant rice varieties. Spring rice cultivation is particularly susceptible to pests such as wild boars and birds, given that it occurs during the off-season

25. Upland Paddy

The Upland paddy was promoted to diversify the maize-based cropping system and to grow rice in their locality. Upland paddy is popular in the east, especially in the dry rainfed areas. It not only serves as a solution to the farmers facing irrigation problems but also gives choices to our consumers in the market. It is a drought-tolerant variety and shall remain an option to mitigate the impacts of climate change on agriculture and enhance the productivity of the rice to ensure self-sufficiency at the household level. The Program was initiated by ARDC Wengkhar in collaboration with Agriculture Extensions in the potential areas.

Figure 19. Upland Paddy cultivation

This technology is a weather smart mainly initiated to sustain in the areas where farmers face acute irrigation water shortage. This program has helped farmers revert their fallow wetlands which were left fallow due to irrigation problems. Upland paddy is suitable to grow in higher regions at an altitude ranging from 1800-3000 masl and the growing season starts from March to October.

Due to its productivity and water stress-tolerant properties, the technology has been successfully adopted by the farmers in the field and is expanding the cultivation areas every year.

A total of 195 households with 116 acres of land produced about 139 MT of paddy in 5 Eastern districts in 2019. An increasing number of farmers, especially the farmers facing acute water shortages and those with limited wetlands are taking up the cultivation of upland paddy. Rice is one of the most preferred crops in the country. Upland paddy has a good yield with 1-1.97 MT/acre and is drought tolerant which enables our farmers to take up the program.

26. Sunken Greenhouse

The Department of Agriculture has initiated a range of protected cultivation techniques to produce year-round vegetables and to increase production. However, conventional greenhouse gases do not protect crops from severe winter conditions. To address this issue, sunken greenhouse has been established in colder regions to grow vegetables and extend their growing season to achieve vegetable self-sufficiency. The basic features of a sunken greenhouse include a desirable greenhouse set, sturdy structural materials to withstand heavy snow, simple ventilation, and an irrigation system. The greenhouse is constructed at a deeper level to harness the earth's constant temperature and is specially designed to operate effectively in colder climates.

Figure 20. Sunken Green-house technology

It is weather-smart technology as the technology that harnesses solar energy to provide a consistent, warm, and conducive environment even in winter enhancing the production of fresh vegetables year-round for smallholder farmers residing in colder regions. A sunken greenhouse system ensures natural insulation that boosts plant growth under extreme cold conditions, unlike conventional farming methods that are influenced by varying climatic conditions and can be built in a variety of sizes.

This technology will benefit smallholder farmers and women enabling them to produce fresh vegetables during off-season fetching premium prices as well. However, the technology involves high establishment costs and the need for experienced persons for initial setup.

27. Chatbot Technology in Agriculture

Chatbot is a computer program intended to simulate conversation with the users, with the use of the internet. Thus, it conducts an online chat conversation through text message or text message to voice message among users. As per the command from the user, the program gives a prompt response. Chatbot technology is widely used in e-businesses for reservation and payments. In the field of Agriculture, Chatbot technology has been used to provide sufficient services related to plant protection, soil nutrient management, crop management practices, and marketing. ARDC Wengkhar initiated the chatbot technology under a protected structure to operate, control, and monitor basic hydroponics features like ceiling and exhaust fans. From two types of Chatbots, Rule-based Chatbots**,** Chatbots without AI (Artificial Intelligence), and AI-based Chatbots (Machine learning Chatbot), ARDC Wengkhar developed a rule-based Chatbot that follows pre-design rules in the program without AI functionality.

The technology is developed from electronic hardware components. Arduino Ide, ESP8266 microcontroller, and Telegram Messenger as application software. Utilization can be done through smartphones (Android and iPhone) or computers (PC, Mac, and Linux). The technology may fall in the knowledge smart category due to its effective utilization in agriculture services in controlling and monitoring activities and devices. The cost of the technology is low, however, the construction and installation of the technology need a skilled person. The technology is suitable in any kind of geographical zone and agroecosystem and can be used by all.

28. Hydroponics technology

Hydroponics is a soil-less and nutrient-rich crop cultivation technology developed at the ARDC in the year 2018 with fund support from the Commercial Agriculture and Resilient Livelihoods Enhancement Program (CARLEP-IFAD/MoAF) and European Union – Rural Development and Climate Change Response Program, MoAF (EU-RDCCRP/MoAF).

There are five different types of hydroponics techniques: Nutrient Film Technique-NFT, Sprinkler Based Vertical Hydroponics System-SBVHS, Deep Water Culture-DWC, Medium-based Pot method, and Trough method. So far hydroponics has been cultivated under protected conditions. The main features of hydroponics are a prefabricated greenhouse structure, exhaust, and ceiling fan. Different hydroponics techniques have different features. However, hydroponics techniques in general have a grow chamber, nutrient solution reservoir, delivery system, and semi-automated or automation system. The choice of automation system can depend on the farmers based on the scale of farming.

This technology falls under the water and nutrient smart category as there is effective utilization of water and nutrients for crop production. It is mainly focused on the landless and to attract youth in agriculture. The main objective of the technology is to get more production from small areas. The selection of crops depends on season and market demand and it must be of high value. However, the initial cost of establishment is high and only the literate farmers can operate. Smallholder farmers can take up the technology as there is certainly more production from small areas. However, the technology must be utilized for a commercial purpose to get additional benefits. The technology is women-friendly due to its nature of less or no drudgery compared to other farming works. The challenges are the high initial cost, the need for literate users, and the requirement for technical skills for installation.

29. Rangzhin Bupmen (Bio-pesticide)

Rangzhin Bupmen is a homemade biopesticide that improves crop yield while lowering the cost for farmers and reducing the use of harmful chemicals. Rangzhin Bupmen is based on local traditional practice in Nepal that is being promoted by ICIMOD as an alternative environmentally friendly and low-cost technology highly applicable in organic farming in the Himalayas. It is prepared using animal urine and locally available plants with a bitter, sour, or pungent smell. This technology was released in 2021 by the National Centre for Organic Agriculture in Bhutan.

Figure 21. Artemisia based bio-pesticide

Rangzhin Bupmen can be categorized as nutrient smart under CSA. It improves plant health and controls pests of crops and protects against fungal and vector diseases. It is a technology suitable for organic farmers to control the pest in their farms. Biopesticides require higher rates of application for controlling pests, thus more labor is required as compared to the use of chemical pesticides. As more farmers are now aware of the ill effects of chemical pesticides on health, the use of Rangzhin Bupmen as an alternative is being accepted. Over a hundred farmers from Bongo village and Ramthangka under Chhukha and Paro districts respectively were trained both theoretically and hands-on training on the preparation of Rangzhin Bupmen in 2022. This technology can be used for all crops for all the agroecological zones in any geographical area. The preparation time depends on the temperature; the warmer the ambient air temperature, the shorter the preparation time.

Bio-pesticides can be prepared easily at the household level. Most farmers own cattle and women are usually in charge of everyday livestock management on farms. This technology is appropriate and suited for both smallholder farmers and women in general. It is a low-cost and eco-friendly bio-pesticide and due to its nature of composition, it also helps in the improvement of soil nutrients. The estimated material cost is Nu.15 per litre and the cost of production is Nu. 16 per litre which translates to Nu.16,000 per acre when applied with the recommended dosage. As the country is committed to promoting organic farming through the National Organic Flagship Program (NOFP), the adoption of this technology is likely to occur with proper awareness and training initiatives for farmers.

30. Rangzhin Luechu 1 (Bio-fertilizer)

Rangzhin Luechu 1 is liquid organic manure that can be frequently applied in organic farming. It is considered an excellent source of nutrients which contains: natural carbon, biomass, nitrogen, phosphorus, potassium, and micro-nutrients. It is prepared by fermentation of a combined mixture of cow dung, cow urine, brown sugar (jaggery), flour, soil, and water. This technology was released in 2021 by the National Centre for Organic Agriculture.

Figure 22. Cow dung-based bio-fertilizers

With the rising cost of imported chemical fertilizers, Rangzhin luechu 1 can be used as an alternative to reduce imports of costly mineral fertilizers. It can be categorized as nutrient smart under CSA and it can be applied as a bio-fertilizer for improving both soil fertility and soil health. This technology will be beneficial to farmers who manage their farms organically as it is accepted in organic agriculture farming. It can be prepared easily at the household level by farmers as the raw materials are readily and locally available and it is suitable for all crops in all the agro-ecological zones. As compared to other manures, compost, and vermicompost, it can be prepared within 4-5 days and has proven to be more effective, but has a shorter shelf life and requires more labour if not automated with a drip irrigation system.

Farmers have been applying imported chemical fertilizer to improve agriculture production, and with supply disruptions faced in the country, Rangzhin luechu 1 can be adopted as an alternate source. In 2021, sixteen farmers of Model Organic Village (MOV) of Nganye village, under Lhuentse district adopted the technology, which will be used as a product for improving their soil fertility in their organic farms. Most farmers have few animals on their farms and it is easy to prepare this biopesticide (4-5 days fermentation) using locally accessible raw materials, making it most suitable for smallholder farmers.

The cost of production for 1 litre of Rangzhin luechu 1 is Nu. 25 or Nu 2,500 per acre, where 250 litres mixed with water (1:1) can be applied directly or through a foliar spray. With the escalation of the price of imported chemical fertilizer and its non-availability in the market, the Rangzhin Luechu 1 technology will directly benefit smallholder farmers as the cost is low compared to chemical fertilizers. Farmers will also readily adopt the technology if they are made aware and trained on the preparation, usage, and benefits of the Rangzhin luechu 1.

31. Vermicomposting

Vermicomposting in the country was introduced by the National Soil Service Centre (NSSC). It is a simple technology that converts biodegradable waste into organic manure with the help of earthworms (*Eisenia foetida*). Earthworms feed on aged manure or organic wastes and excrete the wastes as castings (worm manure), an organic material rich in nutrients that look like fine-textured soil, which is an excellent source for beneficial soil microorganisms, micronutrients, plant enzymes, and plant growth hormones. Vermicomposting is being promoted as climate-smart agriculture (CSA) technology for developing organic nutrient sources that can be adopted by smallholder farmers (Sinazo et al., 2022).

Figure 23. Vermicomposting technology

Vermicomposting can be categorized as nutrient-smart CSA technology as the castings can be used as organic fertilizer for agriculture crop production, floriculture, and landscaping, thereby reducing the use of chemical fertilizers. The vermicomposting process does not eliminate weed seeds, therefore, it is necessary to either avoid seeds in the input material or utilize a combination of thermophilic and vermicomposting processes for production. As compared to other composting technology, it is costlier and requires more care and attention.

This technology is recommended for geographical areas with environmental requirements of temperature 4-30℃, moisture content 60-90%, and in fully aerobic conditions. It is suitable for agriculture enterprises such as floriculture, horticulture, and nursery business. Farmers have been practicing traditional composting for application in their farms. Vermicomposting will be a value-added product to their existing practice, as it has comparatively higher nutrient contents compared to traditional composting. Few farmers produce vermicompost on a small scale and few successful commercial products are also available in the market. As vermicompost is higher in its nutrient value as compared to other traditional composts, less quantity of vermicompost application is required. Smallholder farmers and women can easily produce it and reduce their reliance on the consumption of mineral fertilizers.

A private firm called Bhu-Org Farm was established in 2015, and it is a registered organic farm in the country. It is one of the few farms that produce vermicompost for commercial purposes. The establishment of such enterprises has led to employment opportunities in the locality and helped in giving a product option to agriculturists in improving their soil fertility. Marketing has never been an issue due to the higher demand for the product. The commercially available vermicompost cost Nu. 20 - 50 per kilogram. The technology is organic, highly effective, and able to substitute mineral fertilizers. It has a higher demand in urban cities for both urban gardeners and garden enthusiasts. This results in more market opportunity as compared to other composts. However, some farmers are reluctant to adopt this technology due to religious beliefs concerning the utilization and mortality of earthworms. 33. Composting

Composting is the natural process of turning organic materials like leaves and food scraps into a useful fertilizer. Composts are humus-like material products formed after the decomposition of organic materials. Composting improves soil health, prevents soil erosion, and promotes healthier plant growth. Farmers in Bhutan who own cattle mostly practice traditional composting.

Composting can be categorized as water and nutrient-smart and it not only increases the water content and retention of sandy soils but also increases aeration and water infiltration of clay soils. It also encourages the production of beneficial bacteria and fungi that break down organic matter to create humus which is a rich nutrient-filled material. To control the spreading of pests, frequent turning of the compost piles is required for the destruction of fly larvae, which can be carriers of potential disease vectors.

Figure 24. Composting of organic materials

Windrow and aerated static pile composting are affected by ambient temperatures and weather conditions. Compost production is more favourable for cooler climate areas. If the temperature of the composting exceeds 70°C during the process of decomposition, the activity of the thermophilic organism responsible for decomposition stops. The technology is suitable for application in all crops for increasing production.

Most farmers usually practice traditional composting, where they use farm yard manure to mix with other available plant materials. According to RNR statistics 2019, the adoption rate for the use of manure/compost is 94.84%. Composting is a straightforward technology and traditional method being practiced by farmers, where livestock manure is mixed with plant materials. It is widely practiced by smallholder farmers for crop production.

32. Aeroponics

Aeroponics is a method of growing plants without soil. The roots are suspended in the air and irrigated with a nutrient-dense mist. In aeroponic systems, roots are provided with a mist of nutrient-dense water solution at regular intervals to produce healthier plants and for faster growth to increase yield. It is an effective and efficient way of growing plants with little water (95% less water than traditional farming methods) and requires minimal space than the most efficient hydroponic system. In Bhutan, an aeroponics system was introduced at the National Seed Centre in 2012 to produce potato mini-tubers fund support from the Bhutan Potato Development Project (BPDP) to restore the potato program by providing healthy and disease-free potato mini-tubers as the seed potato of the country was almost infected with viral and bacterial disease leading to the decline in quality as well as yield.

Figure 25. Potato tuber production in Aeroponics

The basic principle of aeroponic technology is to grow plants suspended in a closed or semi-closed environment and mist/spray roots and lower stems with an atomized nutrient-rich water solution from the solution storage tank using a pump with a timer setup. The nutrient solution after being sprayed onto the roots is collected at the bottom of the growth chamber and flows back into the tank. In this manner, the nutrient solution is re-used. The aeroponic system mainly comprises three main components i.e. growth chamber, plant supporting portion, and the nutrient supply system. Structurally, there are four types of aeroponics viz; seedbed type, vertical barrel type, prototype, and pyramid type.

It is weather-smart as it is operated under protected structures. Water and nutrients are smart as they are supplied on a calculated and timely basis where every drop is utilized without wastage. It is also knowledge-smart as the technology deviates from conventional methods to ensure quality and quantity crop production at unfavourable locations. The technology can be implemented or applied in almost all regions of the country where access to fertile and healthy soil medium is difficult and water scarcity is an issue. High-value crops such as potato mini-tubers, tomatoes, lettuces, green leaves, and other herbs can be grown throughout the year by providing adequate nutrients and water for faster growth and maturity of the crops. At the NSC aeroponics facility, the potatoes are planted during February/March and can be harvested from June to September.

Currently, the aeroponic system is not entirely implemented among local farmers as the initial investment and operating costs are huge and the commodities chosen are usually high-value crops. In Bhutan, it has been implemented and adapted only at the institutional level at the National Seed Centre where mini-tubers of potatoes are produced for restoring the varietal purity and high health disease-free seed potato tubers. Although the initial cost of the establishment is high, it can be operated by women as it does not require hard labour. The smallholder farmers (mostly registered seed growers) are direct beneficiaries of the technology as they receive clean and healthy potato seeds.

The advantages of this technology are year-round cultivation, fast plant growth, better quality, less requirement of nutrients and water, and disease-free produce. In potatoes, the mini-tuber production is around ten times more than the conventional system. Support from the government through cost-sharing mechanisms and loan provisions with lower interest rates for aspiring individuals and institutions will increase the adoption of this technology. The requirement of technical knowledge and the high cost of establishment are some of the challenges.

33. Tissue Culture

Plant tissue culture refers to the collection of techniques used to maintain or grow plant cells, tissues, or organs under sterile conditions in a nutrient culture medium of known composition. It is widely used to produce clones of a plant through micropropagation. It is a quick and easy way to generate disease and pest-free, genetically identical, and large numbers of healthy plants in a laboratory. In Bhutan, a plant tissue culture laboratory was established way back in 1988 at the National Seed Centre with the objectives of raising mass plant species and also for the plants having difficulty raising through traditional methods.

It mainly comprises basic facilities such as equipment and apparatus, washing and storage facilities, media of preparation room, sterilization room, an aseptic chamber for culture, culture rooms or incubators fully equipped with temperature, light, and humidity control devices, and observation or recording area well equipped with computers for data processing. An explant (a portion of the plant body from any vegetative part of the plant) is sterilized and cultured for mass propagation of hundreds and thousands of plants in a continuous process in a short period under controlled conditions, irrespective of the season and weather on a year-round basis.

Figure 26. Banana Tissue culture technology

Tissue culture technology is weather-smart as it is carried out under protected structures. It is also water and nutrient-smart as they are supplied only as per requirements. It is knowledge smart as huge quantities of plants are produced in a short period from a limited area. It is a technology best fit for addressing production issues and adaptation in the face of changing climatic conditions.

Suitable to all geographical locations of the country where clean environment and physical space for farming is an issue. High-value crops and crops that are in high demand in the market can be quickly multiplied and supplied through tissue culture. High-quality potato microtubers, banana, apple rootstock, strawberry, asparagus, pear, flowers like rhododendron, begonia, orchids, grapes, and other high-value crops can be multiplied any time of the year from the facility.

Currently, the tissue culture technique is not widely practiced in the farmers' field as the initial investment and running costs are huge, and it demands technical skills. Tissue culture products like bananas were widely promoted and are currently grown by farmers across the country. The new banana variety Grand 9 (G-9) was introduced in the country through tissue culture in 2015 and around 50,000 banana seedlings have been distributed so far while successive disease-free seed potato tubers (30,000 per year) produced through potato micro-tubers are supplied to the farmers.

The production and distribution of disease-free banana and potato tubers have helped thousands of farmers across the country to generate income. Previously, the government and NSC in particular could not meet the demand for potato tubers and bananas through normal production due to the constraints of arable land and human resources. Mass production through tissue culture technology has helped address this issue. The main benefits are mass production of disease/pathogen-free plants by micro-propagation, continuous year-round production, and the ability to change specific conditions to meet the needs of a particular plant species such as nutrient, light, and temperature requirements.

The government strongly supports the promotion of new and viable technologies through cost-sharing mechanisms, low-interest/collateral credit schemes, and capacity-building and promotional programs. The technology is labour-intensive and an expensive process requiring high investment, only selected plants can be multiplied through tissue culture, inadequate advanced tissue culture laboratory facilities, infrastructures, and lack of skilled manpower.

34. Low-cost plastic-lined water harvesting pond

Inadequate irrigation water is one of the main constraints for agriculture in most parts of Bhutan. To minimize the water shortage in agriculture, this technology is proposed. The proposed technology is an adaptation and improvement over the pond lining introduced by Himalica (2014) at Barshong, Tsirang. It has been modified and improved to suit the topography and needs of farmers in Bhutan by ARDC Bajo. The proposed pond design is in a reverse truncated rectangular pyramid shape, unlike the cuboid-shaped ponds of Himalica. The pond is designed in such a way as to increase the pond's stability and ease of construction.

Figure 27. Water harvesting technology

This technology is an adaptive technology to enhance water use and management. To tap the runoff and excess water, a supplementary pond to the conventional water supply system, low-cost plastic-lined water harvesting ponds can store the untapped water resource economically and efficiently. Rain gutters, small seasonal springs, rain-water drainage systems, and excess water outlet points are major sources of water for the ponds. This technology benefits farmers with increased water availability for crop production and livestock use. It increased the affordability and availability of water by farmers which will result in the decrease of disputes among farmers over water use. Further, low initial and maintenance costs encourage farmers to adopt this technology for agricultural purposes. A low-cost plastic-lined water harvesting pond is suitable for use in dryland agriculture including both marginal and commercial farmers for vegetable/fruit/cereal cultivation across the country during dry winter.

Most of the citrus farmers of Tsirang, Dagana, Wangdue, and Punakha use this pond. Further, vegetable and other fruit growers are also widely adopting this technology where there is an irrigation water shortage. Some farmers in Dagana have further modified the pond designs to suit their water use needs for drinking, fish culture, and livestock besides farming. Women at Drujeygang have not only expanded their vegetable garden after the construction of water harvesting ponds but also started winter vegetable cultivation which they had not practiced earlier. The technology helped to increase the cultivation area and its production by 73% and 76% respectively in Tsirang. Further, support for plastics on a cost-sharing basis by different donor projects has enabled the farmers to adopt this technology. However, water seepage resulting from rodent damage on plastics is one of the challenges.

35. Rice Husk Biochar

Low nutrient status of farm soils, shortage of inputs for organic agriculture, and soil degradation due to heavy use of chemical fertilizers are some of the major constraints. This technology is proposed as organic input for soil management. Rice husk biochar is produced from the pyrolysis of rice husks in a modified kiln (cone, barrel, and chimney) adopted from Japanese technology by ARDC Bajo. Its use has been largely due to its application as a carbon sink, soil amendment, water retention, and other agricultural uses.

Figure 28. Rice-husk biochar (L) and field visit to bio-char production site (R)

This technology is suitable for mitigation and adaptation to climate change. It helps to conserve soil carbon, and sequestrate carbon from organic matter through pyrolysis. This technology also improves the soil health for sustainable soil and increases productivity through enhanced nutrient and water retention capacity of the soils. The converted carbon from organic matter is indefinitely stable, slowing the atmospheric greenhouse gas levels. The pre-charged biochar improves soil health and habitat for beneficial microbes in soil which increases crop productivity. It has been also used for soil mulch or amendments in acid soils and potting media. This technology is suitable for all levels of agriculture enterprises such as floriculture, horticulture, and nursery businesses across the country. Places with no rice cultivation can also use other kinds of husks. The rice husk biochar is widely used in west-central districts of Bhutan including Zhemgang, Trongsa, and Samtse. ARDCs also use it for nursery and other research.

The technology is beneficial to the smallholder as well as commercial farmers. It offers enterprise opportunities to women in floriculture, horticulture, and nursery business which are generally their pet projects. The rice husk biochar is widely used as a potting mix component, soil amendment, hydroponics substrate/media, and mulch. Enhanced nursery health of plants at the research level is demonstrated. Farmers also reported decreased incidences of soil-borne diseases with increased yield in crops such as chilli, cole crops, and maize in Wangdue and Punakha districts.

The input support from the Government and different projects that advocate organic and sustainable agriculture, climate change mitigation, and soil conservation have enabled the farmers to adopt this technology. The wide uses as soil amendment, potting mix component, hydroponics media, and soil mulch through Extension dissemination as well as farmer-to-farmer information transfer have aided in the adoption of this technology.

36. Rice-bran Bokashi

Low nutrient status of farm soils, shortage of inputs for organic agriculture, and soil degradation due to heavy use of chemical fertilizers are some of the major constraints in agriculture. The proposed technology is an adaptation of Japanese technology by the Integrated Horticulture Project/Agriculture Research and Development Centre-Bajo. This technology involves the fermentation of Rice-Bran by adding beneficial microbes such as lactic acid bacteria, photosynthetic bacteria, and yeast.

 

Figure 29. Rice-Bran Bokashi production and application of Bokashi in the field

This technology is for soil carbon conservation and sustainable soil management for increased crop productivity. This technology is also for integrated pest management. Use of Rice-bran *Bokashi* can be used as an organic substitute for chemical fertilizers for sustainable soil management while also helping conserve soil carbon. In a research demonstration, Rice-bran *Bokashi* was seen to suppress wilt diseases and enhance yield in chilli. This technology is suitable for all levels of agriculture enterprises such as floriculture, horticulture, and nursery business.

The technology is widely used in west-central districts of Bhutan including Zhemgang, Trongsa, and Samtse. ARDCs also use it for nursery and other research. Some farmers have also started as enterprises earning Nu.100 per kilogram of Rice-bran *Bokashi.* It is beneficial to the smallholder as well as commercial farmers. It offers enterprise opportunities to women in floriculture, horticulture, and nursery business which are generally their pet projects.

The Rice-bran *Bokashi* is widely used as a potting mix component, and organic fertilizer in west-central Bhutan for vegetable cultivation. Floriculture enterprises are largely seen to consume this input as an alternative to forest topsoil and leaf moulds. Enhanced nursery health of vegetables was reported by researchers at ARDC Bajo. Further, improved yield in chilli (about 135% yield increase) over chemical fertilizers applied at equivalent N-contents with suphala. Farmers also reported decreased incidences of soil-borne diseases with increased yield in crops such as chilli, and cole crops in Wangdue, Dagana, and Punakha districts.

The input support from the Bhutan Government and different projects that advocate organic and sustainable agriculture, climate change mitigation, and soil conservation have enabled the farmers to adopt this technology. This technology may not be easily adopted at places where livestock is a major sector due to competition on the use of Rice bran.

37. Bhutan Agriculture Microbial Solution (BAMS)

The unavailability of organic inputs for soil nutrients and pest management is a major constraint of organic farming. To make different organic inputs available for use in organic farming, BAMS is proposed. BAMS is similar to EM solution and consists of beneficial microbes like yeasts, lactobacillus, and photosynthetic bacteria. It is used for extracting plant nutrients, bokashi preparation, as a composting enhancer, as a deodorant, and in the fermentation of cattle urine. This technology is an output of the Integrated Horticulture Promotion Project and ARDC Bajo.

Figure 30. Microbial Solution

This technology enhances productivity to improve nutrition security and build resilience to adapt to climate change. BAMS shifts the microbial diversity of the soils, enhances the quality, shortens the process of composting, and is used as a deodorant in cow urine fermentation. This technology is suitable for all levels of agriculture enterprises such as floriculture, horticulture, and nursery business. It is widely used in west-central districts of Bhutan including Zhemgang, Trongsa, and Samtse in Rice-bran *Bokashi* making, hydroponics, cow urine fermentation at ARDC, Wangdue, Tsirang, and Dagana. It is advocated by the National Soil Service Centre, National Centre for Organic Agriculture, and ARDCs as an important input for Organic agriculture, and sustainable agriculture.

The technology is beneficial to the smallholder as well as commercial farmers. It offers enterprise opportunities to women in floriculture, horticulture, livestock, composting enterprises, and nursery business which are generally carried out by women. Further, it reduces the costs of composting, enhances the working environment, improves soil health, and better yields empowering women with income opportunities and safety. Composting has been shortened to a few weeks from a few months when used as *Bokashi*. Suppression of foul odour of composts, cowsheds, and farms is also reported. The use of BAMS as fermented rice bran has been shown to improve soil health, crop yield, and disease suppression in Wangdue.

The input support from the Government and different projects promoting climate-smart technologies have enabled the farmers to adopt this technology. The first-hand benefits from the use of these practices such as reduction of composting time and costs, improved plant health, and enhanced crop productivity are the main reasons for its adoption.

Conclusion

The exploration and inventory of climate-smart agriculture technologies in Bhutan reveals a promising path towards sustainable agricultural practices in the face of climate change. The document has highlighted a range of innovative technologies that hold the potential to enhance agricultural resilience, reduce greenhouse gas emissions, and ensure food security in the country. The integration of weather forecasting systems, improved irrigation techniques, and the adoption of drought and flood-resistant crop varieties showcase Bhutan's commitment to adapting its agricultural sector to changing climatic conditions. Furthermore, the emphasis on soil and water management practices underscores the importance of holistic approaches that not only mitigate environmental impact but also promote ecosystem health and biodiversity.

The success of these climate-smart agriculture technologies hinges on the collaboration between government agencies, local communities, research institutions, and private sectors. The document underscores the need for policy support, capacity building, and knowledge-sharing platforms to effectively implement and scale these innovations. As Bhutan aims to achieve its sustainable development goals, the adoption of climate-smart agriculture technologies stands as a critical step towards ensuring long-term agricultural viability, preserving natural resources, and safeguarding the livelihoods of its farming communities. By embracing these technologies, Bhutan can inspire other nations to take proactive measures in the realm of climate adaptation and mitigation, fostering a more resilient and environmentally conscious global agricultural landscape.

Recommendations

Capacity building

There is a need to invest in capacity development through training programs for the Agricultural extensions, researchers, and local communities on CSA technologies so that they will have adequate knowledge and information on managing and implementing CSA technologies effectively. The capacity building may include workshops, exposure visits, training, seminars, and demonstrations. Farmer’s exposure visits to other South Asian countries are highly recommended so that they can share knowledge and experience at their level of farming.

Support research and innovations

The Himalayan nations are highly vulnerable to changing climatic conditions and need constant research and innovative technologies to overcome the daily impact of climate change. To continue with the research and generation of new technology, there is a need for both technical and financial support.

Incentivization of CSA technologies

The CSA technologies adopted in Bhutan are cost-intensive and mostly not affordable by the common farmers. The initial investment needs to be subsidized so that it becomes affordable and can be adopted by the farmers. This can alleviate the initial financial burden and incentivize widespread adoption.

Weather advisory services

There should be an efficient platform to disseminate weather advisory services to enhance the accessibility of weather and climate information to farmers through mobile apps, SMS services, or radio stations. Timely and accurate information will enable farmers to make informed decisions related to planting, irrigation, and other agricultural practices.

Modalities to scale up CSA technologies

Need to carry out extensive research on scalability and farmer's willingness to adopt the technologies. Some technologies turn out to be viable in terms of overcoming the impacts of climate change but may not be profitable to scale up at the community level.

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