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ROYAL UNIVERSITY OF BHUTAN

COLLEGE OF NATURAL RESOURCES

Training Manual

Climate-Smart Agriculture Practices for Water-Stressed Areas

Training Manual: Climate-Smart Agriculture Practices for Water-Stressed Areas

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Introductory Note

This Climate-Smart Agriculture (CSA) Training Manual has been developed to equip lead farmers, community leaders, and extension agents with the knowledge and skills needed to address the unique challenges of farming in water-stressed areas. Climate change has intensified water scarcity in many regions, threatening crop productivity, food security, and rural livelihoods. Through practical guidance, this manual introduces proven CSA practices that help farmers adapt to changing conditions, optimize limited water resources, and build resilient agricultural systems.

The manual combines scientific knowledge with locally relevant solutions, focusing on techniques such as climate-resilient crop selection, efficient irrigation methods, soil and water conservation, and the use of innovative tools like ICT and IoT in farm water management.

By applying the approaches outlined in this manual, farming communities can strengthen their capacity to adapt with climate variability especially leading to water stress and safeguard natural water resources.

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1. Introduction

The climate data for Bhutan from 1951 to 2020 shows a clear and accelerating warming trend in both annual average minimum and maximum surface air temperatures. Minimum temperatures have risen from just above 4°C in the early 1950s to nearly 6°C by 2020, while maximum temperatures have increased from about 12.8°C to roughly 15°C over the same period (Figure 1& 2). In both datasets, trend lines indicate that the rate of warming has accelerated, most markedly since the 1990s, with the steepest slopes observed for the 1991–2020 period. This suggests that Bhutan is experiencing faster warming in recent decades, in Bhutan's diverse and sensitive mountain environments. Over the long term (1950–2020), annual precipitation in Bhutan has shown a declining trend. However, from the 1970s onwards, precipitation levels have generally increased, with a sharper rise observed since the 1990s (Figure 3).

Climate change poses significant challenges to agriculture, especially in water-limited areas where unpredictable rainfall, droughts, and extreme weather events threaten crop production and livelihoods. The extreme events in Bhutan have increased many folds over the years as shown in Figures 1& 2. To address these challenges, climate-smart agricultural practices are essential for building resilient farming systems that can adapt to changing conditions while reducing their environmental impact. This manual focuses on a range of strategies—from cultivating climate-resilient crops and varieties, adopting water-efficient irrigation technologies, and implementing soil and water conservation practices like mulching and contour farming, to using organic amendments such as compost and biochar. It also highlights the role of innovative tools like ICT and IoT in optimizing water use, as well as risk management approaches like crop insurance and community water management groups that strengthen farmers' capacity to cope with climate variability. Together, these practices and technologies support sustainable agriculture, enhance food and nutritional security, and promote resilience in water-scarce environments.

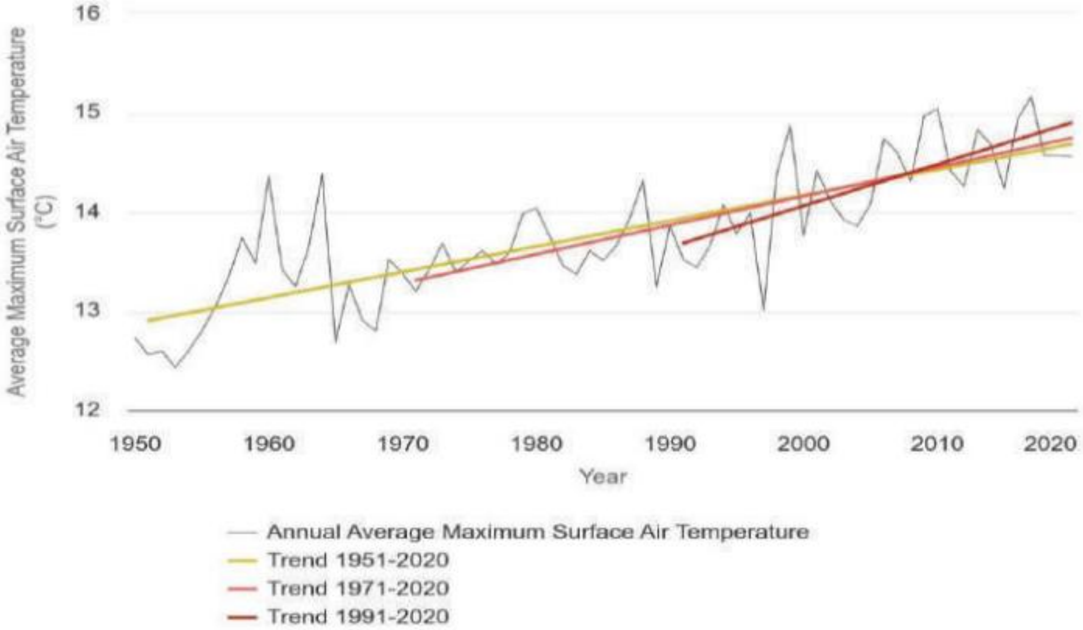

Figure 1: Annual Average Maximum Surface Air Temperature (Source: Data source: NCHM, Bhutan Climate Projection Report)

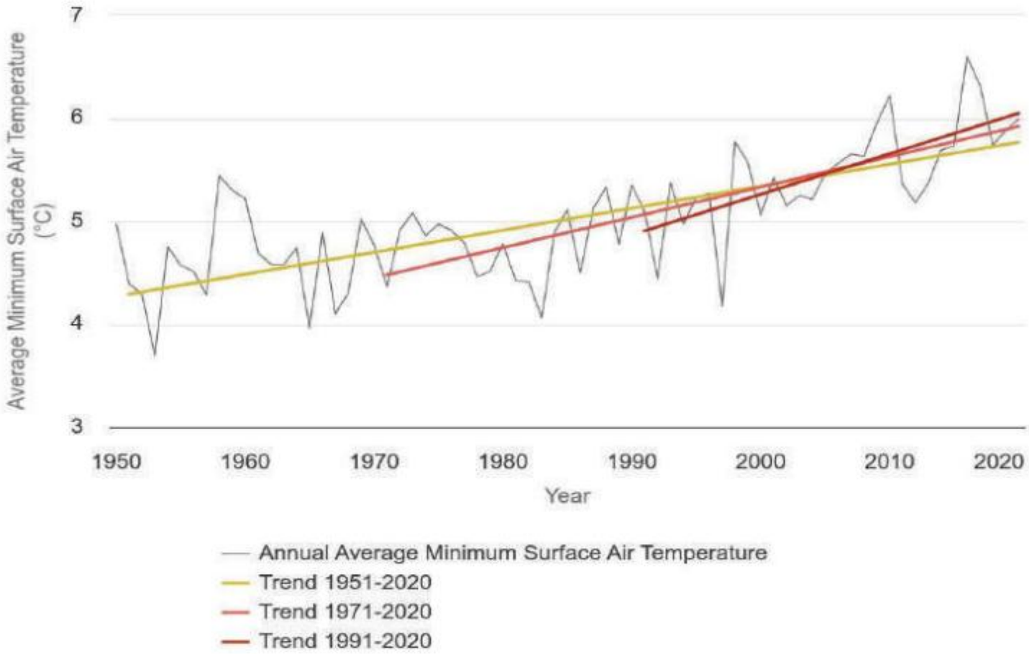

Figure 2: Annual Average Minimum Air Temperature

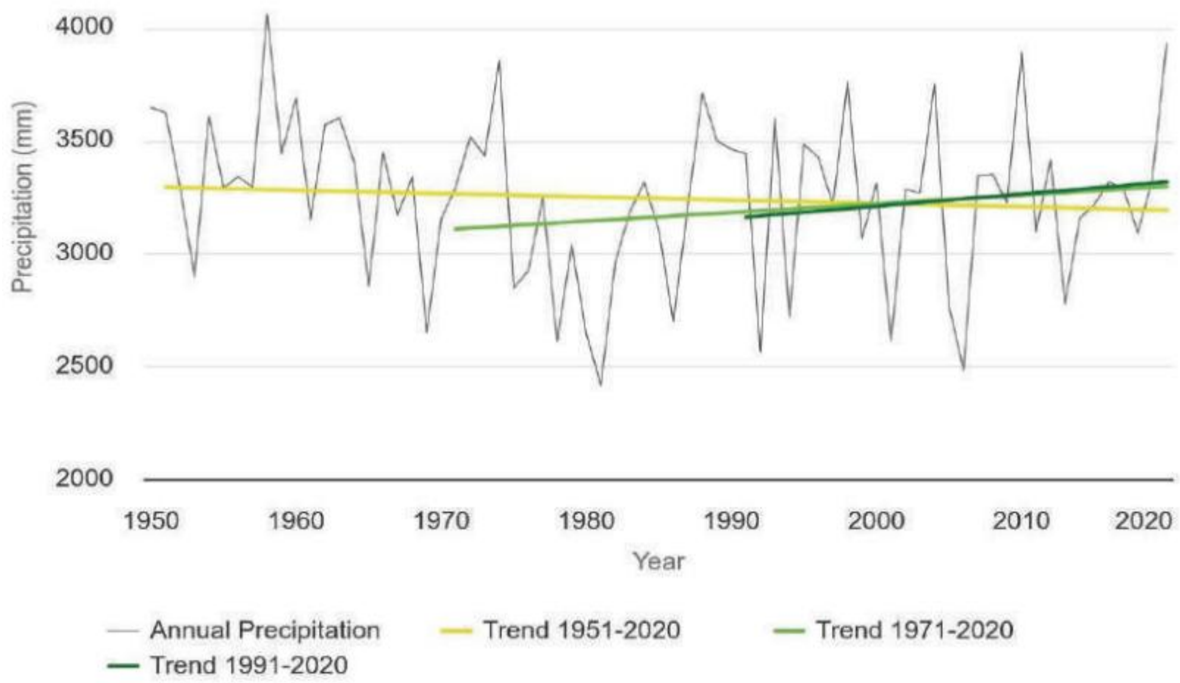

Figure 3: Annual Precipitation (Data source: NCHM)

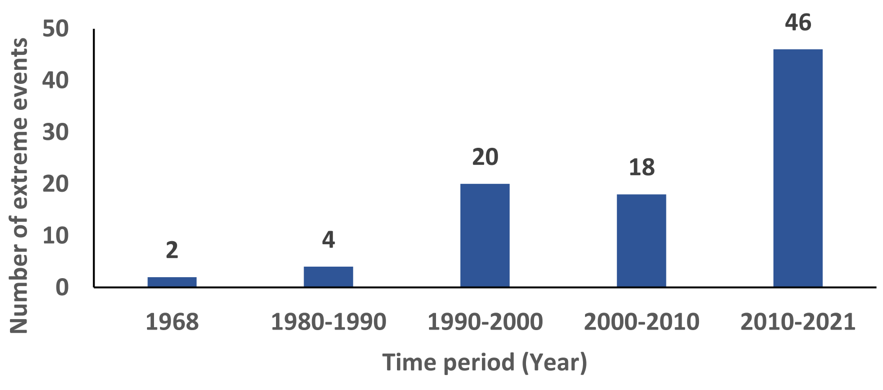

Figure 4: Number of extreme events over the decades

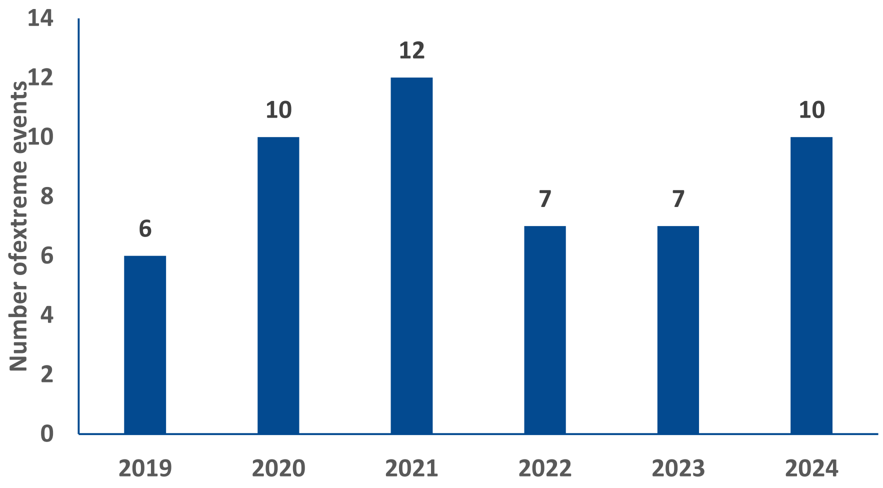

Figure 5: Number of extreme events in recent past 5-6 years

2. Climate Resilient Crops and Varieties

Climate-resilient crops are those which are naturally adapted to withstand the impacts of climate change, such as extreme temperatures, irregular rainfall, droughts, or floods. These crops are typically hardy, require fewer inputs, and are better suited for marginal environments. Examples include millets, buckwheat, barley, quinoa, and certain pulses like chickpea and lentil. The climate resilience comes from traits like deep rooting systems, short growing periods, and tolerance to poor soils. By promoting the cultivation of climate-resilient crops, farming systems can become more sustainable and better equipped to cope with climate variability, ensuring food and nutritional security for farming populations.

Within the crops, there are varieties which are more tolerant to droughts and other abiotic stresses. Generally, traditional crop varieties are hardy and more resilient to environmental and edaphic stresses, as they evolved over centuries through natural and farmer-led selection, with a wide range of genetic traits that help them adapt to diverse and harsh environments. Such varieties are also adapted to the local climate, soil, and farming practices, making them better suited to unpredictable weather patterns. Unlike HYVs, which require high levels of inputs to achieve their potential, traditional varieties perform well under low-input or organic systems, making them more sustainable in resource-constrained environments. However, there are several HYVs which are bred to be climate resilient and can be used. Below (Table 1) is a brief description of such crops and varieties.

3. Early Maturing Varieties

Early maturing crop varieties are considered climate-resilient because their shorter growth cycles allow them to escape or avoid the impacts of climate stress. Early maturing crops complete their life cycle before the peak of seasonal droughts, heat waves, or rains, thus reducing the risk of crop failure. They also provide flexible planting windows as farmers can plant and harvest these crops in a shorter time, allowing more flexibility to adjust to delayed or erratic rainfall patterns. Because they grow faster, early maturing varieties often require less water over their lifecycle, making them suitable for water-scarce or rainfed areas. A shorter field duration means the crop is exposed to pests and diseases for less time, reducing the risk of infestations. In many regions, early maturing varieties make it possible to grow more than one crop per season, improving food security and farmer income. In brief, early maturing varieties help crops "escape" climate stress rather than resist it, making them an effective tool in adapting to changing climate. Below (Table 2) is a short summary of early maturing crops and their varieties suitable for our local conditions.

Table 1: Climate resilient crop varieties

Crop	Trait/Category	Varieties
Rice	Drought Tolerant	Khangma Maap, Bhur Kambja, Bhur Kambja 2, Wengkhar Kambja 1, 2, 3
	Cold Tolerant & Blast Resistant	Yusirey Kaap 1, 2, 3; Yusirey Maap 1, 2; Yusirey Kathra-Mathra
	High Yield & Blast Resistant	IR 64, Bajo Kaap 1, 2, 3; Bajo Maap 1, 2; Wengkhar Rey Kaap 1, 2; Bhur Rey Kaap 1, 2
	Yield Stability (Marginal Areas)	BR 153
Maize	Disease Tolerant	Chaskarpa, Shaphangma (GLS & Turcicum Blight)
	High & Stable Yield	Yangsipa, Wengkhar HTM 1 (heat tolerant hybrid)
Wheat	Disease Tolerant	Bajosokha 1, Bajo Kaa 3, Gumasokha Kaa
	Cold Tolerant	Bumthang Kaa Drukchu
Millet	Climate Resilient	Limithang Kongphu 1, 2; Memja 3
Quinoa	Climate Resilient & Nutritious	Ashi Heychum AM, AS, Ivory, TW

Pulses	Mungbean	Limithang Mung 1, 2
	Soybean	Khangma Libi 1, 2
	Beans	Wengkhar Semchu 1, Bajo Semchu 1-P
	Broccoli	Dessico, Green Magic
	Bulb Onion	Bajo Gop, Wengkhar Gop
	Cabbage	Golden Acre, Lucky Ball, Red Ruby (hybrid)
	Cauliflower	Wengkhar Metokopi 1, 2; Pragato 40; Carotena (hybrid)
	Chilli	Samtenling Ema 1, 2; Yangtsipa Ema
Vegetables	Carrot	Wengkhar Lhaphu Maap, New Kuruda
	Tomato	Bajo Lambenda 1, 2, 3; Samtenling 1, 2

Table 2: Early maturing crop varieties

Crop	**Varieties**
Rice	IR20913, No 11, Barkat, Samtenling Rey Kaap 3, Sokha Rey
Maize	Bhur Ashom 1, Baby Corn (hybrid)
Millet	Memja 1
Mustard	Yusi Peka 1, 2

4. Intercropping and Crop Rotation

Intercropping and crop rotation reduce agriculture's carbon footprint, build soil resilience and increase the adaptive capacity of farming systems in combating climate change. Intercropping, which is growing two or more crops together in the same field, helps to fight climate change through improved soil health as different crops contribute diverse root structures and organic matter and enhance soil fertility. Crops with complementary water and nutrient needs reduce pressure on soil and water resources, making agriculture more resilient during droughts or erratic rainfall. Intercropping lowers greenhouse gas emissions from soils due to reduced dependence on chemical fertilizers. Diverse cropping systems naturally suppress pests and diseases, and reduce the need for chemical pesticides. Multiple cropping systems buffer against crop failure, that is, if one crop fails due to climate stress, the other may still yield, thus enhancing food security. Some examples are provided in Table 3.

Crop rotation is growing different crops in sequence on the same land, contributes to climate resilience by breaking pest and disease cycles as rotating crops interrupts the lifecycle of pests and pathogens. Alternating deep and shallow-rooted crops promote soil aeration and organic matter buildup, storing more carbon in the soil. There is an improved nutrient cycling using legumes and cover crops to fix nitrogen and enhance nutrient availability. Intercropping leads to greater resilience to climate variability by maintaining long-term soil health and productivity. Water use efficiency can be enhanced by rotating crops with varying water demands and help manage soil moisture more effectively, especially under erratic rainfall patterns. Some examples are provided in Table 4. Alley cropping is common in some regions (Figure 6).

Table 3: Intercropping

Type	Description	Example
Row Intercropping	Different crops planted in alternating rows	Maize + Soybean
Mixed Intercropping	Crops grown together without distinct rows	Maize + Beans + Pumpkin
Strip Intercropping	Crops planted in strips wide enough to manage separately	*Maize + Soybean (Strip Format)*
Relay Intercropping	Second crop planted before the first is harvested (overlapping growth)	Maize + Soybean
Agroforestry intercropping/alley cropping	Annuals crops are grown between the rows of fruit tress	Mandarin + vegetables (Figure

Table 4: Crop rotation (Example)

Year	Plot A	Plot B	Plot C	Plot D
1	Beans (Legumes)	Chillies (Fruit)	Cabbage/broccoli	Radish/Carrot
2	Radish/Carrot	Beans (Legumes)	Chillies (Fruit)	Greens (Leafy)
3	Greens (Leafy)	Radish/Carrot	Beans (Legumes)	Cabbage/broccoli
4	Cabbage/broccoli	Greens (Leafy)	Radish/Carrot	Beans (Legumes)

Figure 6: Alley cropping

5. Soil and Water Conservation Practices

5.1 Mulching

Mulching or the covering of soil surface with organic or inorganic materials is a simple practice that supports both climate change mitigation and adaptation. It plays a vital role in sustainable agriculture by improving soil health, conserving water, and reducing the need for external inputs. Organic mulches like crop residues, straw, leaves, or compost decompose over time, adding organic matter to the soil (Figure 7). This process increases soil organic carbon levels, locks CO_2 from the atmosphere into the soil, helping to reduce greenhouse gas emissions. Mulch acts as a protective barrier, significantly reducing soil moisture loss due to evaporation. It helps to lower the frequency of irrigation and reduces water stress in rainfed farming systems, improving climate resilience in water-scarce regions. Mulching moderates extreme soil temperatures by insulating the soil. Mulch naturally suppresses weed growth and minimizes the need for herbicides. Mulching also prevents soil erosion and runoff, supports biodiversity and soil micro-organisms. Thus, mulching is a low-cost, low-tech practice with high climate impact. Plastic mulches are getting popular among the commercial farmers as it is easily available and also promoted by the government (Figure 8).

Figure 7: Straw mulching

Figure 8: Plastic mulching and drip irrigation

The structure called Cloche or Mini Green House (Figure 9) acts like a mini-greenhouse or cloche, trapping heat and moisture to create a warmer microclimate for the plants, protecting them from cold, wind, pests, and excessive evaporation. It is a simple, low-cost method often used in climate-smart farming to extend the growing season and improve seedling survival in challenging weather conditions.

Figure 9: Cloche/mini green house

5.2 Contour farming and terracing

Contour farming and terracing are traditional yet highly effective land management practices that enhance climate resilience in sloping and hilly agricultural landscapes (Figure 10). Contour farming involves ploughing and planting along the natural contour lines of the land, rather than up and down slopes. Terracing converts steep slopes into a series of flat or gently sloped fields. Both practices slow down surface runoff, allowing water to infiltrate and reduce leaching of fertile topsoil. By reducing runoff, contour farming and terracing improve water infiltration into the soil, increasing moisture availability for crops. In rainfed farming systems, these practices support more stable crop yields during periods of water stress. Terraces act as barriers that reduce the velocity of rainwater, preventing flash floods on slopes. These practices help reduce land degradation and desertification, major threats linked to climate change and poor land use. Contour farming and terracing are thus essential climate-resilient practices, especially in mountainous or sloping regions like Bhutan.

Figure 10: Terracing of sloping land (Source: NSSC, Bhutan)

Figure 11: Vegetative measures for contour farming

5.3 Conservation Tillage Practices

Conservation tillage refers to a set of farming practices that minimize soil disturbance and maintain soil cover, typically through methods such as minimum tillage, zero tillage, or strip tillage (Figure 12). Unlike conventional ploughing, which disrupts soil structure and leaves land bare, conservation tillage supports climate resilience by improving soil health, reducing erosion, and enhancing water retention. Less soil disturbance allows organic residues to accumulate and decompose naturally. This increases soil organic carbon, improves soil structure and fertility, contributing to climate change mitigation through carbon sequestration. Undisturbed soils with organic cover absorb rainwater more efficiently, reducing runoff and water loss. It reduces soil erosion and land degradation; this is critical under climate change, which often brings more intense storms and rainfall events. Conservation tillage reduces the need for machinery passes across the field, cutting fossil fuel use and emissions from tractors. Also, reduced tillage preserves soil life, including earthworms, fungi, and microbes. Conservation tillage is therefore a core component of climate-smart agriculture, offering multiple co-benefits: improved soil health, reduced emissions, and greater resilience to drought and extreme weather.

Figure 12: Conservation tillage practices (Picture source: Internet)

5.4 Organic manure and compost

Organic manure and compost are natural soil amendments made from decomposed plant and animal materials. Unlike synthetic fertilizers, they nourish the soil biologically, offering both climate change mitigation and adaptation benefits. Organic manure and compost enhance soil organic matter, which helps trap and store atmospheric CO_2 in the soil, a key climate change mitigation strategy known as carbon sequestration. Rich in microbial life, compost improves soil biodiversity, texture, and structure. Such healthy soil is better at retaining water and nutrients, making crops more resilient to droughts, heat waves and floods. When organic waste is composted aerobically (with oxygen), it reduces methane emissions that would result from anaerobic decomposition in landfills or manure pits. Soils enriched with compost and organic manure can hold more water, reducing irrigation needs. This is especially critical in areas experiencing erratic rainfall or prolonged dry spells due to climate change. Organic fertilizers recycle nutrients from plant and animal waste back into the soil, and build resilient farming systems, leading to more stable crop yields even under climatic stress. By enhancing carbon storage, reducing emissions, improving soil water retention, and promoting sustainable nutrient cycles, organic fertilizers support both mitigation and adaptation in climate change fight.

Vermicomposting is a climate-resilient agricultural practice that uses earthworms to convert organic waste into nutrient-rich compost, improving soil health and fertility (Figure 13). By recycling crop residues, animal manure, and household organic waste, it reduces the need for synthetic fertilizers, thereby lowering greenhouse gas emissions associated with their production and use. Vermicompost enhances soil structure, water-holding capacity, and microbial activity, making crops more tolerant to droughts and extreme weather events. Additionally, it provides a low-cost, locally adaptable solution for smallholder farmers, supporting sustainable farming systems and contributing to both climate change mitigation and adaptation.

Figure 13: Vermicomposting

5.5 Biochar

Biochar (Figure 14) is a stable, carbon-rich material produced by heating organic biomass (such as crop residues, wood chips, or other organic substances) in a low-oxygen process called pyrolysis. When applied to soil, biochar offers benefits for both climate change mitigation and adaptation. Biochar is highly stable and does not decompose easily, allowing carbon to be locked in the soil for hundreds to thousands of years. This makes it one of the most effective tools for removing CO_2 from the atmosphere and storing it safely in terrestrial ecosystems. Biochar can reduce emissions of nitrous oxide and methane from soils which are both potent greenhouse gases. Producing biochar recycles agricultural and forestry waste, converting potential emissions sources into a long-term carbon sink. Biochar improves soil porosity and water-holding capacity, which helps crops withstand droughts and reduces irrigation needs. It enhances the retention of nutrients (especially nitrogen and phosphorus), reducing leaching and improving crop resilience to nutrient stress. Biochar also neutralizes acidic soils and improves degraded or nutrient-poor soils, expanding the land usable for agriculture under climate stress. Biochar mitigates climate change by sequestering carbon and reducing emissions, and helps farmers adapt through improved soil health, water retention, and crop resilience.

Figure 14: Biochar production and use

5.6 Cover Cropping

Cover crops are plants grown primarily to protect and improve the soil rather than for harvest. They provide multiple benefits that contribute to both mitigating the causes of climate change and adapting to its impacts. Cover crops add organic matter to the soil through their roots and plant residues, which increases soil organic carbon, helping to store atmospheric CO_2 in the soil. Legume cover crops like clover or vetch fix nitrogen from the air, reducing the need for synthetic fertilizers, which are major sources of nitrous oxide emissions. By capturing leftover nutrients and preventing leaching, cover crops reduce nitrogen losses into the environment, which helps control both emissions and water pollution. The root systems of cover crops improve soil structure and porosity, allowing better water infiltration and retention (Figure 14). This helps buffer crops against droughts and erratic rainfall. Cover crops protect the soil surface from heavy rain and wind, reducing erosion. Cover crops support beneficial microbes, earthworms, and overall soil biodiversity. Healthy soils are more resilient to climate stress and better at cycling nutrients naturally. A living mulch of cover crops suppresses weeds and can reduce pest populations, lowering the need for herbicides and pesticides. Cover crops are thus a climate-smart solution that improves soil health, enhances farm resilience, and reduces agriculture's climate footprint.

Figure 15: Cover crop (Picture source: Wikipedia)

6. Water efficient irrigation techniques

6.1 Drip irrigation

Drip irrigation is a highly efficient climate-smart agricultural technology that delivers water directly to the root zone of plants through a network of pipes, tubes, and emitters, ensuring minimal losses from evaporation, runoff, or deep percolation (Figure 15,16 &17). This precision application optimizes water use, making it particularly valuable in drought-prone and water-scarce regions, where climate change is intensifying competition for limited water resources. By providing a steady and controlled supply of moisture, drip irrigation reduces crop water stress, enhances nutrient uptake, and supports consistent yields even under erratic weather patterns. There are mainly two types 'inline' and 'online' drip system. In inline system, the emitters are built into the drip tubing at fixed intervals. This is ideal for evenly spaced crops like vegetables or closely planted orchards. On online system, separate emitters are attached to the lateral lines, allowing customized placement for trees or irregularly spaced plants.

It also lowers energy consumption compared to traditional flood irrigation, thereby reducing greenhouse gas emissions associated with pumping. Furthermore, targeted watering limits weed growth, minimizes soil erosion, helping to preserve soil health and fertility. Through its ability to conserve water, improve productivity, and reduce environmental impacts, drip irrigation effectively addresses the adaptation, mitigation, and productivity goals of climate-smart agriculture, making it an essential tool for building resilience in farming systems under changing climatic conditions.

Figure 16: Laying out the drip irrigation pipes: Inline Drip Irrigation

Figure 17: Inline drip irrigation

Figure 18: Online drip irrigation

6.2 Sprinkler irrigation

It is a climate-smart agricultural technology that enhances water-use efficiency, supports crop productivity, and helps farmers adapt to the impacts of climate change. By distributing water uniformly and in controlled amounts, it minimizes losses from runoff and deep percolation, ensuring that crops receive the right amount of moisture even during irregular rainfall or drought periods. This efficient use of water reduces pressure on scarce resources while lowering the energy required for pumping, which in turn helps cut greenhouse gas emissions. Sprinklers also prevent waterlogging, salinity buildup, and soil erosion, thereby protecting soil health and maintaining its long-term productivity. By ensuring reliable irrigation, improving crop health, and conserving natural resources, sprinkler irrigation contributes to all three pillars of climate-smart agriculture (adaptation, mitigation, and productivity) making it a sustainable and resilient option for farming in a changing climate (Figure 18).

Figure 19: Sprinklers (Picture Source: Internet)

6.3 System of Rice Intensification (SRI)

The System of Rice Intensification (SRI) is an innovative cultivation method designed to enhance rice productivity while reducing water usage (Figure 19). It involves transplanting younger seedlings (less than 15 days old) individually with wider spacing (25–40 cm apart), which not only promotes better root and plant development but also facilitates manual weeding using simple tools. Water management relies on alternate wetting and drying (AWD) method, as it is proven that rice does not require standing water in the field all the time. Depending on the soil type, irrigation is done only the soil shows minor cracks. As it requires significantly less water than traditional methods, SRI is considered an effective climate change adaptation strategy for rice farming.

Figure 20: System of rice intensification (Picture source: Internet Guidelines for SRI for tropical countries & ILSI, India)

6.4 Rain water harvesting

Rainwater harvesting is a climate-smart technology that involves collecting and storing rainwater from rooftops, land surfaces, or catchment areas for later use in irrigation, livestock, and domestic needs. It helps farmers adapt to changing rainfall patterns and prolonged dry spells by providing a supplementary water source during periods of scarcity. By reducing dependency on unreliable seasonal rainfall and over-extraction of groundwater, rainwater harvesting strengthens water security and resilience against droughts. It also mitigates flood risks by capturing runoff, preventing soil erosion, and enhancing groundwater recharge. As a low-cost, environmentally friendly, and locally adaptable technology (Figure 20, it supports sustainable water management and contributes to climate change adaptation in both rural and urban settings.

Figure 21: Rain water harvesting, using a plastic-lined pond to store water

6.5 Solar power-based lift irrigation

Solar-powered lift irrigation is a climate-smart technology that uses solar energy to pump water from rivers, wells, or other sources to fields located at higher elevations. By replacing diesel or electricity-driven pumps with solar-powered systems, it reduces greenhouse gas emissions, lowers energy costs, and ensures a reliable water supply even in off-grid or remote areas. This technology enables farmers to irrigate during dry spells, stabilize crop production, and diversify farming systems, thereby enhancing resilience to climate variability. Solar lift irrigation also minimizes operational costs after installation and reduces dependence on fossil fuels, making it a sustainable and environmentally friendly solution for climate change adaptation and mitigation in agriculture.

Figure 22: Solar powered lift irrigation system

7. Springshed management

Springshed management is a climate-smart tool that safeguards and restores the natural recharge zones of springs to ensure reliable water supply in the face of changing rainfall patterns and prolonged dry spells. By protecting recharge areas through measures such as afforestation, controlled grazing, and regulated land use, communities can enhance infiltration, reduce erosion, and maintain year-round water availability. In Chhukha district, for example, protecting uphill catchment forests has helped revive drying springs that supply drinking water to villages. Similarly, in the mid-hills of Nepal, planting native deep-rooted trees like alder and stabilizing slopes with broom grass have improved groundwater recharge. Practices such as digging contour trenches, constructing check dams, and diverting rainwater into infiltration pits have been successfully applied in Uttarakhand and Sikkim to slow runoff, increase percolation, and boost spring yields. These interventions not only secure drinking water but also support climate-resilient agriculture by ensuring a steady supply for irrigation, thereby enhancing productivity while protecting ecosystems.

Figure 23: Spring shed recharge trenches (Source: Down to Earth and nature based solutions, Bhutan)

8. IoT and ICT Tools for Water-Smart Farming

Water-smart farming aims to optimize water use in agriculture to increase productivity while conserving water resources. Information and Communication Technology (ICT) and the Internet of Things (IoT) play a transformative role in achieving this goal. These tools help farmers make informed, real-time decisions to enhance water efficiency, reduce waste, and adapt to climate variability. Below in Table 5 is a summary of such tools.

Table 5:ICT tools for water smart farming

ICT Tool	Description	Examples / Applications
Mobile Apps & SMS Services	Provide farmers with weather forecasts, irrigation schedules, and drought warnings; recommend when and how much to irrigate based on local conditions and crop needs.	mAgri apps, SMS-based irrigation alerts, local agri-weather advisory services.
Remote Sensing & GIS	Use satellite imagery and GIS maps to monitor soil moisture, vegetation health, and water availability; support irrigation planning, drought stress detection, and evaluation of water-saving practices.	NDVI mapping, soil moisture monitoring via Sentinel-2, GIS-based watershed maps.
Decision Support Systems (DSS)	Integrate weather, soil, and crop model data to guide water-efficient irrigation decisions.	FAO WaPOR, FAO CropWat, AquaCrop.
Digital Extension Services	Offer online training, videos, and advisory content to share water-saving techniques such as drip irrigation, mulching, and alternate wetting and drying (AWD) in rice.	Digital farmer portals, YouTube agri-training channels, WhatsApp advisory groups.

Table 6: IoT Technology for water smart farming

IoT Technology	Description	Benefit for Water Management
Soil Moisture Sensors	Installed in fields to measure real-time moisture levels in different soil layers; irrigation is triggered only when moisture drops below crop-specific thresholds.	Prevents overwatering, saves water, and ensures optimal soil moisture for crops.
Smart Irrigation Systems	Automated irrigation based on sensor data, weather forecasts, and crop needs; can be drip or sprinkler systems integrated with	Delivers water precisely when and where needed, reducing wastage and improving efficiency.

IoT Technology	Description	Benefit for Water Management
	controllers and remotely controlled via mobile.	
Weather Stations	On-farm devices that monitor rainfall, temperature, humidity, and wind speed to guide irrigation scheduling.	Avoids irrigation before rainfall or during high evaporation periods, conserving water.
Drones and UAVs	Equipped with multispectral cameras to detect water stress zones and support site-specific irrigation management.	Targets water application to stressed areas only, optimizing usage.

9. Risk Management and Policy Support

9.1 Crop Insurance

Crop insurance is a financial risk management tool that protects farmers against crop losses due to extreme weather events, pests, and other climate-related risks. While it does not directly reduce greenhouse gas emissions or restore ecosystems, crop insurance plays a critical role in climate change adaptation by enhancing the resilience of farming communities. It provides financial stability in the face of climate shocks such as droughts, floods, storms, and pest and disease outbreaks. Crop insurance helps farmers recover financially after such events, preventing them from falling into poverty or abandoning farming. It also encourages climate-smart investments (climate resilient seeds, breeds or infrastructures like micro-irrigation) by farmers. Crop insurance schemes reduce dependency on emergency relief after a crisis, which can be slow and unpredictable. While not a direct mitigation strategy, crop insurance is a vital tool for adapting to climate change. It shields farmers from increasing climate risks, enables long-term planning, and encourages the adoption of sustainable and resilient agricultural practices.

9.2 Community Water Management Groups

Community Water Management Groups (CWMGs) such as water users associations are local institutions formed to manage water resources collectively and sustainably. In the face of climate change, characterized by erratic rainfall, droughts, floods, and increasing competition for water, these groups play a vital role in building climate-resilient communities in rural areas. CWMGs promote equitable and efficient water use by establishing rules and systems for fair distribution of limited water resources. This prevents overuse and ensures access for all members, especially during droughts or water shortages, enhancing social resilience. They also maintain and improve water infrastructure by taking collective responsibility for maintaining irrigation channels, ponds, tanks, and water harvesting systems. Many CWMGs lead conservation initiatives such as check dams, recharge pits and watershed restoration. These activities improve groundwater recharge, enhance ecosystem resilience, and sustain agriculture under climate stress. CWMGs can also offer platforms for education and training on water-efficient practices. By fostering cooperation, trust, and social cohesion, CWMGs help prevent conflicts over water, especially during shortages.

10. Conclusion

Climate-smart agriculture offers a practical and proven pathway to sustain farming in water-stressed areas by integrating adaptive practices, efficient technologies, and resilient crop choices. Through measures such as water-saving irrigation systems, drought-tolerant crop varieties, soil and water conservation, and ICT/IoT-based decision tools, farmers can maintain productivity while using limited water resources wisely. These practices not only enhance farm resilience against droughts and erratic rainfall but also contribute to long-term soil health, ecosystem balance, and livelihood security. By adopting CSA, farming communities can transform climate challenges into opportunities for innovation, collaboration, and sustainable growth, ensuring food security and water efficiency for present and future generations.