CLIMATE SMART AGRICULTURE, FOOD SECURITY AND SUSTAINABLE DEVELOPMENT

GLOBAL ISSUES & LOCAL PERSPECTIVES volume One

Edited by

Eteyen Nyong

Ijeoma Vincent-Akpu

Bassey Ekpo

Muhammad Hussaini

Udensi Ekea Udensi

Mansur Bindawa

SAEREM BOOK CHAPTERS First Published 2025 ISBN 978-978-60709-8-8 @ SAEREM World

Society for Agriculture, Environmental Resources & Management (SAEREM)

First published 2025

SAEREM World

Nigeria

Typeset in Times New Roman

CLIMATE SMART AGRICULTURE, FOOD SECURITY AND SUSTAINABLE DEVELOPMENT
GLOBAL ISSUES & LOCAL PERSPECTIVES volume One

SAEREM BOOK CHAPTERS First Published 2025 ISBN 978-978-60709-8-8

Printed at: SAEREM World

TABLE OF CONTENTS

SAEREM BOOK CHAPTERS First Published 2025 ISBN 978-978-60709-8-8 @ SAEREM World

Part Two: THE CONCEPT OF FOOD SECURITY

Integrating Agroforestry and Forest Gardens into Urban Greening for Food Security in Nigeria

Dr. Ogunsusi, Kayode

Department Of Forestry, Wildlife And Environmental Management, Olusegun Agagu University Of Science And Technology, Okitipupa, Ondo State, Nigeria

Chapter Eleven

Climate Smart Agriculture, Food Security and Sustainable Development: Homegarden Agroforestry Perspective

*Eric, E.E.,** Ejizu, A.N. and *Akpan, U.F.

*Forestry Research Institutes of Nigeria, Ibadan, Swamp Forest Research Station Onne, Rivers State, Nigeria.

**Forestry Research Institutes of Nigeria, Ibadan, Federal College of Forestry, Ishiaghi, Ebonyi State, Nigeria.

*Corresponding author: estydavies@gmail.com

Chapter Twelve

Impact of Information Communication Technology(ICT) on Revenue Generation in Jalingo Local Government Area, Taraba State- Nigeria.

John Baling Fom, PhD[1] and Atiman Kasima Wilson, PhD[2]
Department of Political Sciences, University of Jos.
Department of General Studies, Federal Polytechnic, Bali

Chapter Thirteen

Role of Climate-Smart Agriculture in Addressing Challenges of Food Security and Climate Change in Africa

[1]KAPSIYA JOEL*, [1]PETER ABRAHAM, [1]ADAMU WAZIRI, [1]DUNUWEL MUSA DANZARIA
*[1]Department of Horticultural Technology, Federal College of Horticulture Dadin-kowa Gombe State Nigeria, *Corresponding author: jkapsiya.hort@fchdk.edu.ng*

Part Three: THE CONCEPT OF SUSTAINABLE DEVELOPMENT

Chapter Fourteen
The Political Economy of Renewable Energy Transitions: Implications for Fisheries

Victoria Folakemi AKINJOGUNLA[1]* and Charity Ebelechukwu EJIKEME[2]
[1]Department of Fisheries and Aquaculture, Bayero University Kano, Kano State, Nigeria.
[2]*Department of Biology, Federal College of Education (Technical), Akoka, Lagos, Nigeria.*
*vfakinjogunla.faq@buk.edu.ng

Chapter Fifteen
Sustainable Agriculture Practices in the Face of Climate Change

Fakuta, B. A, Ediene, V. F and Etta, O. I.
Faculty of Agriculture, University of Calabar, Calabar, Nigeria
Corresponding author: email balthiya1@gmail.com

Chapter Sixteen
Assessing the Challenges of Implementing Climate Change Adaptation Practices in Agricultural Communities of Benue State, Nigeria

Elisha Ikpe[1], Ugbede D. Omede[2] and Patrick A. John[2]

[1]Department of Geography, Federal College of Education, Odugbo, Benue State

[2]Department of Agricultural Science, Federal College of Education, Odugbo, Benue State

Email: elishaikpe@fceodugbo.edu.ng

Chapter Seventeen
Climate Smart Agriculture

Muhammad Usman Mairiga

College of Agriculture and Animal Science

Ahmadu Bello University, Mando Kaduna

Chapter Eighteen

Climate Change and Food Production Threats in Nigeria: A Call for Action

Paul Temegbe Owombo
Department of Agricultural Economics and Extension, Olusegun Agagu University of Science and Technology, Okitipupa, Ondo State, Nigeria; owombopaul@gmail.com

Chapter Nineteen

Evaluating the Impact of Climate Change on Weed Dynamics, Sugar Quality, and Performance of Sugar cane hybrid clones in a Nigerian Savanna

[1]Shittu, E.A*., [2]Bassey, M.S, and [1]Buhari, F.Z

[1]Department of Agronomy, Bayero University Kano, P.M.B 3011, Kano State, Nigeria ORCID: 0000-0003-0639-009X
[2]National Cereals Research Institute, P.M.B 8, Bida, Nigeria ORCID: 0000-0002-9345-1112
*Corresponding Author email: seabarahm.agr@buk.edu.ng

Chapter Twenty

Integrating Crop Farmers Adaptation Stategies Against Climate Change In Ondo State, Nigeria

Emmanuel Olasope Bamigboye and Lateef Ayodeji Ola

Chapter Twenty One

Climate Change Mitigation Strategies Adopted by Palm Wine Tappers in Akwa Ibom State Nigeria

Eteyen Nyong and G. E. Okon

Department of Agricultural Economics, Akwa Ibom State University, Nigeria

eenyong16@gmail.com

Chapter Twenty Two

Pig Production in Nigeria: Current Status, Opportunities, Prospects and Challenges

Adeoye, A. A.

Department of Animal Production and Health, Olusegun Agagu University of Science and Technology Ondo State Nigeria: adeomoh@yahoo.com

Chapter Twenty Two

Pig Production in Nigeria: Current Status, Opportunities, Prospects and Challenges

Adeoye, A. A.

Department of Animal Production and Health, Olusegun Agagu University of Science and Technology Ondo State Nigeria: adeomoh@yahoo.com

SAEREM BOOK CHAPTERS First Published 2025 ISBN 978-978-60709-8-8 @ SAEREM World

Preface

This book adopts an exegetical approach as well as a pedagogic model, making it attractive agriculture and environmental economics teachers, professional practitioners and scholars. It is eschews pedantry and lays bars the issues in such clarity that conduces to learning. The book elaborates on contemporaneous **Climate Smart Agriculture, Food Security and Sustainable Development** issues of global significance and at the same time, is mindful of local or national perspectives making it appealing both to international and national interests. The book explores the ways in which climate smart agriculture (CSA) food security, Sustainable Development issues are and should be presented to increase the public's stock of knowledge, increase awareness about burning issues and empower the scholars and public to engage in the participatory dialogue climate smart agriculture, food security, and sustainable development necessary in policy making process that will stimulate increase in food production and environmental sustainability.

Climate Smart Agriculture, Food Security and Sustainable Development: *Global Issues & Local Perspectives* is organized in three parts. Part One deals with The Concept of **Climate Smart Agriculture**, Part Two is concerned with The Concept of **Food Security And**
and Part Three deals with the Concept of **Sustainable Development**

Eteyen Nyong; October 2025

 ISBN 978-978-60709-8-8 @ SAEREM World

Chapter Twenty Three

Transforming Agriculture Through Climate-Smart Approaches: Pathways to Food Security and Sustainable Development

*[1]Rotimi, E.A. and [2]Patrick, A.J.
[1]Department of Animal Science, Federal University Dutsin-Ma. Katsina state. Nigeria
[2]Department of Agricultural Science Education, Federal College of Education, Odugbo-Benue State, Nigeria; earotimi@gmail.com

1. Introduction

Agriculture is the backbone of human civilization, contributing not only to food production but also to economic growth, employment, and environmental stewardship (FAO, 2023). Globally, the sector employs over 1.3 billion people, representing nearly 40% of the workforce, with the majority in developing regions (World Bank, 2022). In sub-Saharan Africa, agriculture contributes 20–30% of Gross Domestic Product (GDP) and supports the livelihoods of more than 60% of the population, most of whom are smallholder farmers (IFAD, 2021). Beyond food, agriculture underpins trade, rural employment, and ecological balance, making it one of humanity's oldest and most fundamental activities. However, agricultural systems face unprecedented challenges in the 21st century. Climate change, population growth, urbanization, and unsustainable land-use practices have converged to create a triple challenge: feeding a growing population, reducing environmental footprints, and building resilience against climate shocks (IPCC, 2022). Global climate projections warn of a 1.5–2.0°C rise in average temperatures by mid-century, with severe implications for crop yields, livestock productivity, and natural resources (IPCC, 2023). Already, climate-induced shocks such as droughts, floods, and pest outbreaks are destabilizing food systems, worsening poverty, and threatening food security in vulnerable regions. Agriculture is central to both the problem and the solution. The sector contributes nearly one-quarter of global greenhouse gas (GHG) emissions (IPCC, 2022), yet it also holds the potential to drive climate solutions through sustainable land management, carbon sequestration, and resource-efficient practices. Recognizing this dual role, the Food and Agriculture Organization (FAO) introduced the concept of Climate Smart Agriculture (CSA) in 2010. CSA integrates three pillars: (1) sustainably increasing productivity and incomes, (2)

SAEREM BOOK CHAPTERS First Published 2025 ISBN 978-978-60709-8-8 @ SAEREM World

enhancing resilience and adaptation to climate variability, and (3) reducing or mitigating GHG emissions where possible (FAO, 2013). Within this framework, agriculture is no longer only about producing more food but also about building resilient ecosystems and inclusive rural economies. This chapter situates CSA at the intersection of climate adaptation, food security, and sustainable development. It explores global and African perspectives on agriculture and climate change, highlights innovative practices and case studies, and examines the prospects, challenges, and policy pathways for transforming agriculture into a climate-resilient and sustainable sector.

2. Agriculture and Climate Change: Global and African Perspectives

Climate change and agriculture share a deeply interdependent relationship: while agriculture is one of the primary victims of climate variability, it is also a significant contributor to greenhouse gas (GHG) emissions that drive climate change. Globally, agriculture accounts for about 19–29% of total anthropogenic GHG emissions (FAO, 2021), with livestock production, deforestation, fertilizer application, and rice cultivation being the major sources (IPCC, 2022). This dual role makes agriculture both a challenge and a solution in the fight against climate change.

The Intergovernmental Panel on Climate Change (IPCC) warns that agricultural productivity is projected to decline in many regions, particularly in sub-Saharan Africa and South Asia, due to increasing temperatures, droughts, floods, and shifting rainfall patterns (IPCC, 2023). These impacts threaten food security, rural livelihoods, and the achievement of the Sustainable Development Goals (SDGs). In Africa, agriculture remains the mainstay of the economy, employing nearly 60% of the workforce and contributing 20–30% of GDP, yet it is predominantly rain-fed and highly vulnerable to climatic shocks (World Bank, 2022).

2.1 The Nexus Between Agriculture and Climate Change

Agriculture and climate change are intricately linked in a dynamic and bidirectional relationship. On one hand, agriculture is highly vulnerable to climate variability and extremes. Rising temperatures, erratic rainfall, prolonged droughts, flooding, and more frequent extreme weather events directly threaten crop yields, livestock productivity, soil fertility, and water availability. These climatic shifts alter growing seasons, increase the prevalence of pests and diseases, and compromise food security, particularly in regions reliant on rain-fed farming systems. Without effective adaptation, global agricultural productivity could decline by 17% by 2050, with sub-Saharan Africa facing potential losses of up to 30%.

On the other hand, agriculture is also a significant contributor to climate change through the release of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Agricultural activities, including land clearing, deforestation, livestock rearing, rice cultivation, and fertilizer application, emit substantial amounts of these gases. Globally, the sector, together with forestry and other land uses, accounts for about one-quarter of total GHG emissions (IPCC, 2023). Livestock production alone contributes approximately 14.5% of anthropogenic emissions, mainly through enteric fermentation and manure management, while intensive fertilizer usage drives nitrous oxide emissions, and deforestation releases large amounts of carbon (FAO, 2021).

This nexus presents both challenges and opportunities. While climate change threatens the stability of global food systems, agriculture also holds the potential to be part of the solution through climate-smart practices. Approaches such as conservation agriculture, agroforestry, integrated crop-livestock systems, sustainable soil and water management, renewable energy adoption, and low-emission technologies can simultaneously reduce emissions and strengthen resilience. Additionally, improved land management and reforestation enhance carbon sequestration, thereby mitigating climate impacts.

Understanding this nexus is essential for shaping policies, technologies, and innovations that safeguard food security, rural livelihoods, and environmental sustainability. Integrating climate change considerations into agricultural planning is not only vital for the protection of farming systems but also central to achieving global agendas such as the Sustainable Development Goals (SDGs) and commitments under the Paris Agreement.

2.2 Climate Change Impacts on Crop Production

Crop production is highly climate-sensitive, and small changes in temperature and rainfall can have significant impacts.

Temperature effects

Many staple crops have optimal temperature ranges for growth. For instance, maize experiences yield reductions when temperatures exceed 30°C during critical growth stages. Wheat yields are expected to decline by 6% for each 1°C rise in temperature (FAO, 2021). In Africa, heat stress has already shortened growing seasons, leading to lower productivity of maize, sorghum, and millet.

Rainfall variability

Sub-Saharan Africa relies heavily on rain-fed agriculture (over 90% of cultivated land), making it highly vulnerable to rainfall variability (World Bank, 2022). Prolonged droughts in the Horn of Africa and southern Africa have led to repeated crop failures and food insecurity affecting millions. Conversely, excessive rainfall causes flooding, waterlogging, and post-harvest losses.

Pests and diseases

Climate change is driving the spread of pests such as the fall armyworm (*Spodoptera frugiperda*) and desert locusts, which thrive under warmer and wetter conditions. For example, the 2019–2021 desert locust invasion in East Africa devastated crops and pastures, exacerbated by unusual climate conditions linked to the Indian Ocean Dipole (FAO, 2021).

Nutritional quality

Elevated CO_2 concentrations may increase biomass production in some crops but reduce the protein, iron, and zinc content of staples like rice and wheat, threatening nutrition security (Myers et al., 2014).

Overall, crop yields in Africa are projected to decline by 10–20% by 2050 under high-emission scenarios if adaptation measures are not scaled up (IPCC, 2023).

2.3 Livestock and Climate Vulnerabilities

Livestock production is also highly sensitive to climate variability and change. Africa's livestock sector provides income, nutrition, and cultural value for millions, yet climate change threatens its sustainability.

Heat stress

Rising temperatures reduce feed intake, fertility, milk production, and weight gain in livestock. Dairy cattle in East Africa, for example, experience reduced milk yields during prolonged heatwaves. Poultry, which has limited thermoregulation capacity, is also highly susceptible to heat stress.

Water scarcity and pasture decline

Recurrent droughts reduce water availability and degrade rangelands, threatening pastoralist communities in the Sahel and Horn of Africa. Livestock migration often intensifies conflicts over water and grazing resources.

Disease prevalence

Warmer climates favor the spread of vector-borne diseases such as Rift Valley fever, trypanosomiasis, and tick-borne diseases. The expansion of tsetse fly habitats under shifting climatic conditions poses risks to cattle production in parts of sub-Saharan Africa.

GHG emissions from livestock

While vulnerable to climate impacts, livestock are also major emitters of methane through enteric fermentation. Methane is 28 times more potent than CO_2 in terms of global warming potential, making mitigation strategies (improved feeding, breeding, and manure management) critical (FAO, 2021).

2.4 Soil Health, Water Resources, and Biodiversity in Agriculture

Healthy soils, water, and biodiversity form the foundation of agricultural productivity, yet they are increasingly under threat from climate change.

Soil health

Rising temperatures accelerate soil organic matter decomposition, reducing fertility. Droughts intensify soil erosion and desertification, particularly in the Sahel region. Conversely, heavy rains cause nutrient leaching and land degradation. Already, 65% of Africa's agricultural land is considered degraded (FAO, 2021).

Water resources

Agriculture accounts for about 70% of global freshwater withdrawals (FAO, 2021). Climate-induced reductions in river flow and groundwater recharge, particularly in arid and semi-arid zones, are projected to intensify water scarcity. Competition between agricultural, industrial, and domestic water use will increase, especially in countries such as Nigeria, Kenya, and South Africa.

Biodiversity

Agricultural systems rely on pollinators, soil microorganisms, and genetic diversity. Climate change threatens biodiversity by altering habitats and species distribution. For instance, declines in pollinator populations jeopardize fruit and vegetable production, while the erosion of crop genetic diversity reduces resilience to pests and diseases (IPCC, 2022). The interconnection between soil, water, and biodiversity underscores the need for sustainable agricultural practices such as conservation agriculture, agroforestry, and integrated soil fertility management.

2.5 The African Context: Opportunities and Challenges

Agriculture in Africa is at the frontline of climate change impacts, but it also presents significant opportunities for transformation.

Challenges:

High dependence on rain-fed agriculture (90–95% of cultivated land).

Limited access to climate information services, modern technology, and financial resources.

Weak extension services and limited capacity for climate-smart innovations.

Vulnerability of smallholder farmers, who form the majority of producers.

Opportunities:
Africa possesses vast uncultivated arable land (about 60% of the world's remaining), which, if managed sustainably, could boost food security.
Rapid expansion of digital agriculture (mobile-based weather services, precision farming tools) offers pathways to adaptation.
Indigenous knowledge and traditional practices, such as shifting cultivation and water harvesting, provide context-specific resilience strategies.
Regional and continental frameworks, such as the African Union's Comprehensive Africa Agriculture Development Programme (CAADP) and the African Climate Smart Agriculture Alliance, are promoting climate-resilient farming.
The African context reveals a paradox: while the continent is highly vulnerable, it also has immense potential for agricultural transformation through innovation, investment, and policy support.
3. Climate Smart Agriculture: Principles and Practices
Climate Smart Agriculture (CSA) has emerged as an innovative paradigm that integrates productivity, resilience, and environmental sustainability. Unlike conventional agricultural models that primarily emphasize yield maximization, CSA recognizes the multi-dimensional nature of agriculture in the 21st century, where food production must be aligned with climate adaptation, ecosystem health, and mitigation of greenhouse gas (GHG) emissions. This section explores the conceptual framework of CSA and its diverse applications in crops, livestock, forestry, digital farming, and indigenous practices.
3.1 Definition and Framework of CSA
The Food and Agriculture Organization (FAO, 2013) defines Climate Smart Agriculture as an approach that *"sustainably increases agricultural productivity, enhances resilience (adaptation), reduces or removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals."* CSA is not a single set of practices but a framework of principles adaptable to local contexts.
The CSA framework is built on three pillars:

1. Productivity and Food Security. Increasing yields and ensuring food supply stability under changing climate conditions.
2. Adaptation and Resilience. Enhancing the capacity of farming systems to cope with climate-related shocks such as droughts, floods, and pests.
3. Mitigation. Reducing emissions from agriculture through efficient resource use, carbon sequestration, and adoption of low-carbon technologies.

CSA is closely aligned with the Sustainable Development Goals (SDGs), particularly SDG 2 (Zero Hunger), SDG 13 (Climate Action), and SDG 15 (Life on Land). Its framework is flexible, allowing governments, NGOs, and farmers to select practices that address their local socio-economic and ecological realities.

3.2 Crop-Based CSA Approaches

Crop production is highly vulnerable to climate variability, particularly in regions dependent on rain-fed agriculture such as sub-Saharan Africa and South Asia. Crop-based CSA approaches focus on sustainable intensification, diversification, and risk management.

Drought-Resistant and Early-Maturing Varieties

Breeding and adoption of climate-resilient varieties (e.g., drought-tolerant maize, flood-tolerant rice, and heat-tolerant wheat) have helped farmers stabilize yields under extreme conditions.

Conservation Agriculture (CA)

Practices such as minimal tillage, crop rotation, and cover cropping enhance soil fertility, reduce erosion, and improve water retention. CA has been widely adopted in Southern Africa with significant improvements in maize and soybean productivity.

Integrated Soil Fertility Management (ISFM)

Combining organic manure, compost, and judicious use of inorganic fertilizers ensures soil health while minimizing emissions.

Efficient Water Management

Techniques such as drip irrigation, alternate wetting and drying (AWD) in rice, and rainwater harvesting reduce water use while maintaining yields.

Crop Diversification

Incorporating legumes, vegetables, and underutilized crops into farming systems reduces risks, enhances nutrition, and improves soil fertility through nitrogen fixation.

These approaches highlight the “triple win” of CSA: sustaining yields, protecting natural resources, and reducing emissions.

3.3 Climate-Smart Livestock Systems

Livestock production contributes significantly to rural livelihoods but also accounts for nearly 14.5% of global anthropogenic GHG emissions, mainly methane and nitrous oxide. Climate-smart livestock systems therefore aim to balance productivity, adaptation, and mitigation.

Improved Animal Genetics. Breeding heat-tolerant and disease-resistant livestock enhances resilience. For example, indigenous breeds like the N'Dama cattle in West Africa exhibit trypanotolerance and adaptability to harsh climates.
Sustainable Feed and Nutrition. Incorporating high-quality forages, feed additives, and agro-industrial by-products improves feed conversion efficiency and reduces enteric methane emissions.
Manure Management. Biogas digesters convert animal waste into renewable energy while reducing methane emissions and providing organic fertilizer.
Pastoralism and Rangeland Management. Adaptive grazing practices, rotational grazing, and fodder banks prevent overgrazing and restore degraded lands (FAO, 2021).
Animal Health Systems. Strengthening veterinary services and early-warning systems helps control climate-sensitive diseases such as Rift Valley Fever and African swine fever.
Climate-smart livestock interventions simultaneously improve productivity, reduce vulnerability to climate shocks, and lower emissions intensity per unit of product.
3.4 Agroforestry and Ecosystem-Based Adaptation
Agroforestry — the deliberate integration of trees into farming systems — is a core CSA strategy with multi-functional benefits. Trees provide shade, enhance soil fertility, sequester carbon, and diversify farm income.
Soil and Water Conservation: Trees reduce erosion, improve infiltration, and recycle nutrients through deep rooting.
Carbon Sequestration: Agroforestry systems can store 2–4 tons of carbon per hectare annually (Mbow et al., 2014).
Microclimate Regulation: Shade trees buffer crops and livestock against heat stress.
Biodiversity Conservation: Agroforestry enhances on-farm biodiversity by providing habitats for pollinators and natural pest predators.
Livelihood Diversification: Products such as fruits, nuts, fodder, and timber provide income and improve household resilience.
Examples include *Faidherbia albida* parklands in the Sahel, where nitrogen-fixing trees increase cereal yields, and cocoa-agroforestry systems in West Africa that combine tree crops with food crops for both ecological and economic benefits.
3.5 Digital Agriculture and Precision Farming
The digital revolution has introduced transformative opportunities for CSA through data-driven decision-making, automation, and remote sensing.

SAEREM BOOK CHAPTERS First Published 2025 ISBN 978-978-60709-8-8 @ SAEREM World

Precision Agriculture: GPS-guided tractors, drones, and sensors enable site-specific management of inputs (fertilizers, pesticides, irrigation), improving efficiency and reducing emissions (Gebbers & Adamchuk, 2010).
Climate Information Services: Mobile-based platforms provide farmers with localized weather forecasts, early-warning alerts, and advisory services. For instance, in Kenya, the "Digital Green" platform links farmers to real-time climate and agronomic information.
Remote Sensing and GIS: Satellite imagery helps monitor crop health, soil moisture, and land-use change for timely interventions.
Blockchain and Supply Chains: Blockchain-based traceability systems improve transparency in food systems and promote sustainable sourcing.
Artificial Intelligence (AI) and Big Data: Predictive models support decision-making in pest management, climate risk mapping, and resource allocation.
Digital agriculture reduces inefficiencies, enhances resilience through timely adaptation, and opens new markets for smallholders. However, adoption requires supportive policies, affordable technologies, and capacity building.

3.6 Indigenous Knowledge and Traditional Practices

Indigenous and local farming communities have long relied on traditional ecological knowledge (TEK) to adapt to climate variability. Integrating these practices into CSA enhances cultural relevance, sustainability, and community acceptance.
Traditional Water Harvesting: Systems such as *zai pits* in Burkina Faso and *jessour* terraces in North Africa conserve soil moisture and improve crop survival in arid regions.
Mixed Cropping and Intercropping: Farmers in West Africa practice cereal-legume intercropping, which improves soil fertility and reduces risks of crop failure.
Sacred Groves and Community Forests: These indigenous conservation systems maintain biodiversity and regulate microclimates.
Ethnoveterinary Practices: Herbal medicines and traditional livestock management provide low-cost solutions for animal health.
Seasonal Calendars and Indicators: Indigenous knowledge of star patterns, animal behavior, and plant phenology guides planting and harvesting decisions.
Recognizing and integrating indigenous knowledge systems ensures inclusivity, respects cultural diversity, and strengthens CSA outcomes.

4. Case Studies in Climate Smart Agriculture

4.1 Conservation Agriculture in Southern Africa

Conservation Agriculture (CA) has emerged as a critical component of Climate Smart Agriculture (CSA) in Southern Africa, where farmers face recurrent droughts, soil degradation, and declining crop yields. CA is based on three interlinked principles: (i) minimum mechanical soil disturbance, (ii) permanent soil cover with organic residues, and (iii) diversified crop rotations (Kassam et al., 2019).

In countries such as Zimbabwe, Zambia, and Malawi, conservation agriculture has been promoted as a strategy to enhance soil fertility, conserve water, and improve climate resilience. Smallholder farmers in Zambia, supported by the Food and Agriculture Organization (FAO) and the Zambian Conservation Farming Unit, have adopted CA practices with promising outcomes. For instance, maize yields under CA systems were reported to be 20–50% higher than conventional tillage systems during drought years, due to improved soil moisture retention and organic matter content.

Moreover, CA reduces greenhouse gas (GHG) emissions by minimizing soil disturbance, enhancing soil carbon sequestration, and reducing reliance on synthetic fertilizers.. However, adoption remains uneven due to barriers such as labor constraints, access to appropriate equipment (e.g., direct seeders), and cultural preferences for traditional ploughing. Scaling up CA in Southern Africa requires targeted extension services, policy support, and access to affordable inputs.

4.2 Drought-Resilient Maize in West Africa

West Africa is one of the most climate-vulnerable regions in the world, with frequent droughts and erratic rainfall severely threatening food security. Maize, a staple crop for over 300 million people in sub-Saharan Africa, is particularly sensitive to water stress. To address this challenge, international and regional research institutions such as the International Institute of Tropical Agriculture (IITA) and the International Maize and Wheat Improvement Center (CIMMYT) have developed drought-resilient maize varieties under the Drought Tolerant Maize for Africa (DTMA) initiative.

Between 2007 and 2016, more than 200 drought-tolerant maize varieties were released across 13 African countries, including Nigeria, Ghana, Mali, and Senegal. These varieties demonstrated yield advantages of 20–30% over conventional varieties under moderate drought stress, significantly contributing to food security and income generation.

Farmers in northern Nigeria and Ghana, for instance, reported that planting drought-tolerant maize not only improved food availability but also reduced vulnerability to seasonal hunger gaps. Additionally, the varieties exhibited tolerance to common pests such as the fall armyworm (*Spodoptera frugiperda*), enhancing their resilience under climate stress.

Despite these successes, challenges persist. Limited access to quality seeds, weak extension systems, and low awareness among smallholder farmers constrain widespread adoption. Public-private partnerships involving seed companies, governments, and NGOs are essential for ensuring the availability, affordability, and dissemination of climate-resilient maize varieties.

4.3 Pastoralist Adaptation Strategies in the Sahel

The Sahel region, stretching across countries such as Niger, Mali, Burkina Faso, and Chad, is characterized by semi-arid conditions, recurrent droughts, and highly variable rainfall. Pastoralism is the dominant livelihood, with millions of households depending on livestock for food and income.

In response, pastoralist communities have developed adaptive strategies that align with CSA principles. One key adaptation is mobility, where herders migrate seasonally to access better grazing areas and water sources.

Another adaptation is the diversification of herds with drought-tolerant breeds such as the Sahelian goat and the Zebu cattle, which are better adapted to harsh climatic conditions. Additionally, pastoralists have integrated traditional knowledge with modern innovations, such as using mobile phones for weather forecasts and market information, which enables better decision-making.

Development agencies have also promoted pastoralist field schools and community-based rangeland management programs to enhance resilience. In Niger, for example, the “3N Initiative” (*Nigeriens Nourish Nigeriens*) has supported pasture restoration, fodder banks, and water harvesting structures, improving livestock productivity and household food security (FAO, 2023).

4.4 Digital Climate Services for Farmers in East Africa

East Africa has become a hub for digital climate services, leveraging mobile phones, satellite data, and artificial intelligence (AI) to support smallholder farmers in adapting to climate variability. The region’s high mobile penetration and expanding digital ecosystem have created opportunities for delivering real-time, localized, and actionable information to farmers.

One prominent example is the Climate Information Services (CIS) platforms in Kenya and Tanzania, which provide farmers with localized weather forecasts, seasonal predictions, and advisories on planting dates, pest management, and input use. The *Kenya Agricultural Observatory Platform (KAOP)*, for instance, combines satellite imagery with ground-based data to deliver advisory services via SMS and smartphone applications. Farmers using KAOP reported yield increases of 15–20% due to timely decisions on planting and fertilizer application. Similarly, the Digital Green and PlantVillage Nuru initiatives in East Africa integrate machine learning and farmer-to-farmer extension videos to provide localized advice on pest and disease management. During the fall armyworm outbreak, the PlantVillage app helped farmers in Kenya and Uganda identify infestations early and adopt effective control measures, reducing crop losses significantly.

However, barriers remain, including digital illiteracy, gender gaps in mobile phone ownership, and affordability constraints for subscription-based services. Scaling these innovations requires inclusive design, partnerships with local extension systems, and enabling policies for digital agriculture.

5. Prospects and Challenges of Agricultural Transformation

5.1 The Promise of CSA for Food Security

Climate Smart Agriculture (CSA) offers a holistic pathway to ensure food security by addressing the dual challenge of increasing agricultural productivity while building resilience against climate risks. The Food and Agriculture Organization (FAO, 2023) defines food security as a condition in which all people, at all times, have access to sufficient, safe, and nutritious food that meets their dietary needs and preferences for an active life. Agriculture contributes directly to the four dimensions of food security—availability, access, utilization, and stability—all of which are highly vulnerable to climate change (IPCC, 2022).

CSA promotes food security by:

Enhancing Productivity: Adoption of improved crop varieties (e.g., drought-tolerant maize and rice) and sustainable soil management practices (e.g., conservation agriculture, integrated soil fertility management) increases yields even under variable climate conditions.

Strengthening Resilience: CSA helps communities adapt to shocks such as droughts, floods, and pest outbreaks through diversification of crops and livestock, agroforestry, and improved water management.

Mitigating Climate Change: Practices such as agroforestry, improved livestock feeding systems, and reduced tillage sequester carbon and lower greenhouse gas (GHG) emissions, contributing to climate change mitigation while improving ecosystem services.

Stabilizing Livelihoods: By combining traditional knowledge with modern technologies, CSA strengthens rural livelihoods, reduces poverty, and builds adaptive capacity of smallholders, who constitute over 80% of food producers in Africa (IFAD, 2021). Thus, CSA represents not just a set of practices but a systemic transformation of agricultural systems to ensure food and nutrition security in the face of climate uncertainty.

5.2 Barriers to Adoption: Institutional, Financial, and Technical Constraints

Despite its promise, CSA faces significant barriers that limit widespread adoption, particularly in developing countries. These constraints are multi-dimensional and interrelated:

1. Institutional Barriers:

Weak extension services and inadequate farmer training hinder awareness and capacity to implement CSA practices. Fragmented policies across agriculture, climate change, and rural development reduce coherence in CSA planning and execution. Limited land tenure security discourages farmers from investing in long-term CSA practices like agroforestry and soil fertility restoration.

2. Financial Constraints:

Many CSA interventions require upfront investments (e.g., irrigation, renewable energy-powered technologies, resilient seed varieties), which smallholders cannot afford without credit access (World Bank, 2022). Agricultural credit institutions often perceive smallholder farmers as high-risk borrowers, leading to limited financing opportunities. Inadequate insurance markets prevent farmers from protecting themselves against climate-induced losses.

3. Technical Barriers:

Low levels of mechanization and technology adoption persist in many regions, making it difficult to implement precision agriculture or digital climate advisory services. Inadequate access to inputs such as improved seeds, fertilizers, and bio-based pest management products undermines CSA implementation. Knowledge gaps exist around the long-term benefits of CSA, particularly in relation to mitigation outcomes and ecosystem services. These barriers underline the need for systemic investments in capacity building, institutional strengthening, and inclusive financing models to scale up CSA adoption.

5.3 Gender, Youth, and Equity Dimensions in Climate-Smart Agriculture

The inclusiveness of CSA is critical to its effectiveness. Agricultural transformation cannot be achieved without addressing the structural inequalities faced by women, youth, and marginalized groups in agriculture.

Gender Dimensions:
Women constitute nearly 50% of the agricultural labor force in sub-Saharan Africa but face limited access to land, credit, inputs, and extension services (FAO, 2021). CSA adoption is often gender-skewed, as male farmers may have more access to decision-making spaces and technologies. Gender-responsive CSA policies (e.g., targeted subsidies, women-led cooperatives, and inclusive training programs) enhance adoption and equity.
Youth Dimensions:
Africa's agricultural sector is aging, with an average farmer age of over 60 years in some regions. Youth bring innovation, digital literacy, and entrepreneurial drive that can accelerate CSA adoption through agribusiness startups, drone technologies, and digital platforms. However, structural barriers such as land tenure restrictions, limited access to finance, and inadequate training discourage youth engagement in agriculture.
Equity Dimensions:
Vulnerable populations such as indigenous peoples, pastoralists, and resource-poor farmers are disproportionately affected by climate change but are often excluded from CSA policy frameworks. Equity-focused CSA ensures that benefits are shared fairly, avoiding unintended consequences that may exacerbate inequalities. Integrating gender, youth, and equity considerations into CSA design ensures that agriculture transformation is inclusive, sustainable, and socially just.
5.4 Private Sector Engagement and Public-Private Partnerships
The private sector plays a pivotal role in agricultural transformation by bridging the gap between research, innovation, and market-driven solutions. Public-Private Partnerships (PPPs) provide platforms for collaborative investment, risk-sharing, and technology dissemination.
Private Sector Roles in CSA
Input Supply Chains
Private agribusinesses supply climate-resilient seeds, fertilizers, and bio-inputs that drive CSA adoption.
Technology and Innovation
Companies in ICT and digital agriculture provide climate advisory services, precision agriculture tools, and market linkages that enhance farmer decision-making.
Finance and Insurance
Financial institutions and agritech startups are pioneering climate risk insurance, credit scoring models, and blended finance instruments tailored to smallholders.

Public-Private Partnerships (PPPs)
PPPs facilitate infrastructure development (e.g., irrigation schemes, renewable energy for rural areas) by pooling resources from governments, NGOs, and private investors. They enhance knowledge transfer by linking research institutions with agribusiness firms and farmers, fostering co-innovation. Successful PPPs in Africa include the Alliance for a Green Revolution in Africa (AGRA), which collaborates with governments, donors, and agribusinesses to promote CSA practices. However, PPPs must be carefully designed to avoid marginalizing smallholders. Transparent governance, inclusive stakeholder participation, and equitable benefit-sharing are essential for ensuring that CSA adoption through PPPs contributes meaningfully to food security and sustainability.

6. Policy, Governance, and Investment Dimensions

Climate Smart Agriculture (CSA) cannot thrive in isolation. Its successful implementation requires enabling policy environments, strong governance structures, and sustained investment flows. Governments, regional bodies, international development partners, the private sector, and local communities must collaborate to mainstream CSA into agricultural planning and rural development strategies. This section explores how policies, governance mechanisms, and investment frameworks shape CSA implementation globally and in Africa.

6.1 National and Regional Policy Frameworks for CSA

National governments play a central role in setting the stage for CSA adoption by integrating it into agricultural, environmental, and climate change policies. Across Africa and other developing regions, CSA has increasingly been embedded within Nationally Determined Contributions (NDCs) under the Paris Agreement, national agricultural investment plans, and climate adaptation frameworks.

Policy Integration: Countries such as Kenya, Nigeria, Ethiopia, and Ghana have included CSA in their national climate adaptation strategies and food security policies (World Bank, 2022). Ethiopia's *Climate Resilient Green Economy Strategy* explicitly promotes CSA as a pathway to reduce greenhouse gas (GHG) emissions while enhancing productivity. Similarly, Nigeria's *National Agricultural Technology and Innovation Policy (NATIP 2022–2027)* integrates CSA in its priority programs for crop, livestock, and aquaculture sectors.

Regional Frameworks: At the continental level, the African Union (AU), through the Comprehensive Africa Agriculture Development Programme (CAADP), emphasizes CSA as a tool to achieve food security and resilience. The *Malabo Declaration (2014)* committed African leaders to sustainable agricultural growth with a focus on climate

resilience. The Economic Community of West African States (ECOWAS) and the Southern African Development Community (SADC) have also developed regional CSA action plans.
Enabling Governance: National CSA taskforces and multi-stakeholder platforms have emerged to harmonize efforts. For example, Kenya established the *Kenya Climate-Smart Agriculture Strategy (2017–2026)*, which provides a roadmap for scaling up CSA across value chains. Such frameworks demonstrate the importance of aligning CSA policies with broader agricultural modernization, food security, and rural development agendas.

6.2 The Role of International Organizations (FAO, IFAD, CGIAR, AU-NEPAD)

International organizations have been instrumental in mainstreaming CSA across developing regions by providing technical expertise, research outputs, policy support, and funding mechanisms.

Food and Agriculture Organization (FAO)

FAO pioneered the CSA concept in 2010 and has since supported its integration into national policies. FAO's *CSA Sourcebook* provides guidance for governments and practitioners on CSA practices. FAO also spearheads projects such as the *Global Alliance for Climate-Smart Agriculture (GACSA)*, which promotes knowledge sharing and capacity building across countries (FAO, 2023).

International Fund for Agricultural Development (IFAD)

IFAD has prioritized climate adaptation and CSA in its rural development projects. Through the *Adaptation for Smallholder Agriculture Programme (ASAP)*, IFAD has mobilized over US$500 million to help smallholder farmers build resilience using CSA practices (IFAD, 2021).

Consultative Group on International Agricultural Research (CGIAR)

CGIAR, through its *Research Program on Climate Change, Agriculture and Food Security (CCAFS)*, has produced pioneering research on CSA technologies, climate risk management, and climate services for farmers. For instance, CGIAR developed drought-resistant maize and climate forecasting tools that have improved food security in East and West Africa.

AU-NEPAD (African Union Development Agency)

AU-NEPAD promotes CSA through its *African Climate-Smart Agriculture Alliance (ACSAA)*, launched in 2014. The alliance aims to support 25 million African farmers to adopt CSA practices by 2025. It also facilitates policy dialogues and aligns CSA initiatives with CAADP commitments.

6.3 Financing CSA: Green Bonds, Climate Funds, and Agribusiness Investment

Financing remains one of the greatest bottlenecks in scaling up CSA, particularly for smallholder farmers in developing countries. Innovative financing mechanisms are critical to bridge the funding gap.

Green Bonds: Green bonds are fixed-income financial instruments designed to raise capital for environmentally friendly projects. These bonds create opportunities for private investors to support CSA initiatives.

Climate Funds: International climate funds such as the *Green Climate Fund (GCF)*, *Adaptation Fund*, and the *Global Environment Facility (GEF)* provide grants and concessional loans for CSA projects. For example, the GCF approved a US$96 million project in Zambia to enhance climate-resilient agricultural practices among smallholder farmers (GCF, 2021).

Agribusiness and Private Sector Investment: Private agribusiness firms are increasingly investing in CSA through outgrower schemes, contract farming, and corporate social responsibility programs. Digital platforms like M-Farm (Kenya) and FarmCrowdy (Nigeria) connect farmers with markets, credit, and insurance, enabling them to adopt CSA practices.

Blended Finance: A promising approach involves combining public finance, donor support, and private investment. Blended finance reduces risk for investors and increases the scale of CSA adoption. Initiatives such as the *Agriculture Fast Track Fund (AFTF)* under the African Development Bank demonstrate the effectiveness of such models.

6.4 Scaling Up CSA: Extension Services, ICTs, and Innovation Hubs

Scaling up CSA from pilot projects to widespread adoption requires robust knowledge dissemination, capacity building, and innovation systems.

Extension Services: Agricultural extension systems are central to CSA adoption. In countries like Rwanda and Ethiopia, decentralized extension services have been instrumental in training farmers on conservation agriculture, agroforestry, and climate risk management.

Information and Communication Technologies (ICTs)

Digital agriculture tools have revolutionized CSA scaling. Mobile-based platforms such as Esoko (Ghana) and Digital Green (India) deliver real-time weather forecasts, pest alerts, and market prices to farmers. Satellite imagery and remote sensing provide climate risk mapping, enabling farmers to make informed decisions.

Innovation Hubs

Agricultural innovation hubs and incubators provide platforms for research institutions, entrepreneurs, and farmers to co-develop CSA technologies. For instance, the iHub Nairobi and CTA's Digitalization for Agriculture Program support climate-smart innovations across Africa.

Climate Services

Climate information services help farmers anticipate risks and adapt. Programs such as the *Enhancing National Climate Services (ENACTS)* in Ethiopia and Tanzania provide localized weather data for farmers to plan planting and harvesting schedules.

7. The Future of Agriculture in a Changing Climate

The future of agriculture is being shaped by the intersection of technological innovation, sustainability imperatives, and global policy frameworks. With the world's population projected to exceed 9.7 billion by 2050, agricultural systems must produce more food with fewer resources, under increasingly unstable climatic conditions (FAO, 2023; IPCC, 2023). To address these challenges, agriculture must evolve into a resilient, adaptive, and sustainable system that integrates emerging technologies, sustainable value chains, and global commitments to resilience and food security.

7.1 Emerging Technologies (CRISPR, AI, IoT in Agriculture)

Technological innovation has always been central to agricultural transformation. In the 21st century, emerging technologies such as gene editing (CRISPR/Cas9), artificial intelligence (AI), and the Internet of Things (IoT) are redefining the possibilities of climate-smart agriculture.

a. CRISPR and Gene Editing

CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) technology has revolutionized plant and animal breeding by allowing precise, efficient, and relatively low-cost genome modifications (Jaganathan et al., 2020). Unlike traditional breeding or transgenic approaches, CRISPR enables scientists to introduce desirable traits such as drought tolerance, heat resilience, pest and disease resistance, and improved nutrient use efficiency directly into crop genomes (Kumari et al., 2023).

Examples:

Drought-tolerant rice varieties developed using CRISPR in Asia.
Maize and wheat gene-edited for resistance to heat and fungal pathogens.
Livestock applications include editing cattle genes for resistance to trypanosomiasis and enhancing productivity traits.

SAEREM BOOK CHAPTERS First Published 2025 ISBN 978-978-60709-8-8 @ SAEREM World

The implications of CRISPR in climate change adaptation are profound, as it can reduce reliance on chemical inputs, shorten breeding cycles, and support food security under unpredictable climates.

b. Artificial Intelligence (AI)

AI is driving the digital transformation of agriculture through predictive analytics, machine learning, and decision-support systems. By analyzing big data from climate models, soil sensors, and satellite imagery, AI provides farmers with real-time insights for optimizing input use, predicting yields, and managing risks (Kamilaris et al., 2018).

Applications:

AI-based pest and disease detection systems using drone and smartphone imaging.

Climate prediction models that help farmers adjust planting times.

Automated farm machinery (e.g., self-driving tractors, precision sprayers) for resource-efficient farming.

AI is also supporting climate risk insurance schemes, where machine learning models predict crop losses and help design index-based insurance for smallholder farmers in Africa and Asia (Adegoke et al., 2022).

c. Internet of Things (IoT)

IoT involves interconnected devices such as soil moisture sensors, weather stations, drones, and GPS-enabled farm machinery that generate continuous data streams. In the face of climate change, IoT facilitates precision agriculture, enabling efficient resource use (water, fertilizer, pesticides) and reducing environmental impacts (Wolfert et al., 2017).

Examples:

Smart irrigation systems that optimize water use in arid zones.

IoT-enabled livestock monitoring for animal health and welfare.

Climate-adaptive greenhouses with automated control systems.

By combining CRISPR, AI, and IoT, agriculture can transition toward a data-driven, resilient, and sustainable system, capable of feeding a growing population under climate stress.

7.2 Sustainable Value Chains and Circular Agriculture

Agriculture's future lies not only in production but also in the way food systems are structured and managed. Value chains must be redesigned to minimize waste, ensure equity, and reduce environmental impacts.

a. Sustainable Value Chains

Sustainable agricultural value chains integrate environmental, economic, and social sustainability principles. They emphasize efficient production, fair trade, low-carbon logistics, and reduced post-harvest losses. With climate change disrupting food availability, sustainable value chains can increase resilience and reduce vulnerability (Gereffi & Fernandez-Stark, 2016).

Strategies:

Promoting local processing and market linkages to reduce dependence on volatile global markets.

Adoption of renewable energy in food processing and cold chains.

Blockchain for supply chain transparency and traceability.

b. Circular Agriculture

Circular agriculture builds on the principles of a circular economy, where waste from one process becomes input for another. This approach contrasts with the traditional linear "take-make-dispose" agricultural model. Circular agriculture emphasizes resource recycling, nutrient recovery, and closed-loop production systems (de Boer & van Ittersum, 2018).

Examples:

Using livestock manure for biogas and organic fertilizer production.

Converting crop residues into animal feed or bioenergy.

Aquaponics systems combining fish farming with vegetable production.

Circular approaches contribute to climate mitigation by lowering greenhouse gas emissions, enhancing soil fertility, and reducing reliance on synthetic fertilizers. They also improve farmers' income streams by diversifying outputs.

7.3 Resilient Food Systems and Global Agendas (SDGs, COP Commitments)

Agriculture's resilience cannot be divorced from global commitments to sustainable development and climate action. The Sustainable Development Goals (SDGs) and the Conference of the Parties (COP) climate negotiations provide guiding frameworks for future agricultural transformation.

a. Resilient Food Systems

A resilient food system is one that absorbs shocks, adapts to stresses, and transforms in ways that ensure long-term food security and ecosystem health. Resilience requires diversity in production systems, robust infrastructure, inclusive governance, and adaptive capacity at the community level.

Building Blocks of Resilience: These included:

Agroecology and diversified farming systems.

Climate risk financing and insurance schemes.
Strengthened research-extension linkages.
Food system innovations that combine nutrition, sustainability, and climate adaptation.

b. Agriculture and the SDGs

Agriculture directly contributes to SDG 2 (Zero Hunger) but is also linked to SDG 1 (No Poverty), SDG 13 (Climate Action), and SDG 15 (Life on Land) (UN, 2015). Advancing climate-smart agriculture accelerates progress across multiple SDGs by:
Increasing productivity and incomes (SDG 1 & 2).
Reducing emissions (SDG 13).
Conserving ecosystems and biodiversity (SDG 15).

c. Agriculture in COP Commitments

The Paris Agreement (COP21) recognized agriculture's dual role as both a source of emissions and a potential carbon sink. Subsequent COPs have increasingly focused on climate-smart practices, carbon markets, and financing for agricultural adaptation. The Koronivia Joint Work on Agriculture (KJWA), adopted at COP23, reinforced the centrality of agriculture in climate negotiations (FAO, 2022).
Recent commitments at COP27 (Egypt, 2022) and COP28 (UAE, 2023) emphasized:
Scaling up climate finance for agricultural adaptation.
Strengthening food system resilience in vulnerable regions.
Accelerating innovation in low-emission agriculture.

8.0 Conclusion

Agriculture stands at the crossroads of climate change, food security, and sustainable development. The sector is both highly vulnerable to climatic shocks and a major contributor to greenhouse gas emissions. However, it also holds the transformative potential to drive resilience, economic growth, and environmental sustainability. Climate Smart Agriculture (CSA) offers a strategic pathway to balance productivity, adaptation, and mitigation. With Africa holding 60% of the world's uncultivated arable land, the continent has both the challenge and opportunity to lead the next agricultural transformation.
Realizing this potential requires bold action from governments, private sector actors, international organizations, and farming communities. By integrating CSA into policies, scaling up innovations, and ensuring inclusivity across gender and youth groups, agriculture can become a foundation for climate-resilient and sustainable development.

9.0 Recommendations

1. Policy and Governance: Mainstream CSA into national agricultural policies and ensure adequate budgetary allocation for climate-smart programs.
2. Financing: Establish blended finance models and expand access to climate insurance, credit, and subsidies for smallholder farmers adopting CSA.
3. Technology and Innovation: Scale up adoption of emerging technologies (AI, IoT, CRISPR) while promoting indigenous knowledge for locally relevant solutions.
4. Capacity Building: Strengthen extension services, farmer field schools, and digital platforms to improve farmer awareness and adoption.
5. Gender and Youth Inclusion: Design CSA interventions that deliberately target women, youth, and marginalized groups to ensure equity.
6. Regional and Global Collaboration: Leverage frameworks like CAADP, COP commitments, and African CSA alliances to align local actions with global climate goals.

References

Adegoke, J., Ogundeji, A., & Oni, T. (2022). Artificial intelligence and climate risk insurance for smallholder farmers in Africa. *Climate Policy, 22*(4), 513–527. https://doi.org/10.1080/14693062.2021.2002507

de Boer, I. J. M., & van Ittersum, M. K. (2018). Circular approaches to sustainable food systems. *Nature Food, 1*(1), 1–2. https://doi.org/10.1038/s43016-020-00109-8

FAO. (2013). *Climate-Smart Agriculture Sourcebook*. Rome: Food and Agriculture Organization.

FAO. (2022). *Koronivia Joint Work on Agriculture: Outcomes and Opportunities*. Food and Agriculture Organization of the United Nations.

FAO. (2023). *The State of Food Security and Nutrition in the World 2023*. Rome: Food and Agriculture Organization.

Gereffi, G., & Fernandez-Stark, K. (2016). *Global Value Chain Analysis: A Primer*. Duke Center on Globalization, Governance & Competitiveness.

IFAD. (2021). *Transforming Food Systems for Rural Prosperity*. Rome: International Fund for Agricultural Development.

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Geneva: Intergovernmental Panel on Climate Change.

IPCC. (2023). Summary for Policymakers. In: Climate change 2023: *Synthesis Report. Contribution of working Groups I, II and III to the sixth Report of the Intergovernmental Panel on Climate Change.*

Jaganathan, D., Ramasamy, K., Sellamuthu, G., Jayabalan, S., & Venkataraman, G. (2020). CRISPR for crop improvement: An update review. *Frontiers in Plant Science, 11*, 985. https://doi.org/10.3389/fpls.2020.00985

Kamilaris, A., Kartakoullis, A., & Prenafeta-Boldú, F. X. (2018). A review on the applications of big data, artificial intelligence, and IoT in agriculture. *Computers and Electronics in Agriculture, 143*, 23–37.

Kumari, A., Singh, R., & Gupta, P. (2023). CRISPR-based genome editing for climate-resilient agriculture. *Plant Biotechnology Reports, 17*(1), 1–15.

Van Eenennaam, A. L. (2019). Application of genome editing in farm animals: Cattle as a case study. *Journal of Dairy Science, 102*(5), 4250–4270.

Wolfert, S., Ge, L., Verdouw, C., & Bogaardt, M. J. (2017). Big Data in Smart Farming–A review. *Agricultural Systems, 153*, 69–80.

World Bank. (2022). *World Development Indicators: Agriculture and Rural Development*. Washington, DC: World Bank.