

CLIMATE SMART AGRICULTURE, FOOD SECURITY AND SUSTAINABLE DEVELOPMENT

GLOBAL ISSUES & LOCAL PERSPECTIVES volume One

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Society for Agriculture, Environmental Resources & Management (SAEREM)

First published 2025

SAEREM World

Nigeria

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Typeset in Times New Roman

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CLIMATE SMART AGRICULTURE, FOOD SECURITY AND SUSTAINABLE DEVELOPMENT

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

Printed at: SAEREM World

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

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

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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 eschews pedantry and lays bare 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

Chapter Two

Climate Smart Cropping Systems: Pathways to Agricultural Resilience and Environmental Sustainability

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1.0 Foundations of Climate Smart Cropping Systems (CSCS)

1.1 Overview of Climate Change and Its Impact on Agriculture

Global climate change is primarily characterized by rising global temperatures, shifting precipitation patterns, and an increasing frequency and severity of extreme weather events. It represents one of the most profound challenges to human existence and social development in the twenty-first century. Driven mainly by substantial anthropogenic greenhouse gas emissions from sources like fossil fuel combustion, global warming has accelerated, with the rate of temperature increase rising significantly over the last few decades. These changes are collectively known as climate change (Arnell *et al.*, 2019). The consequences—including record-breaking droughts, floods, and wildfires—are already manifesting their impact on communities worldwide.

As the foundation of human survival, agricultural production is uniquely vulnerable to these rapid global shifts. Climate change is already impacting farming and agricultural productivity across the globe, especially in tropical regions, and is projected to have significant effects through both direct and indirect pathways (Yuan *et al.*, 2024). Direct impacts include the alteration of environmental factors such as temperature, precipitation, and wind speed, which disrupt crop growth cycles, hasten maturity, and affect quality. Indirect impacts manifest as a higher incidence of disasters, such as floods and droughts, which destroy farmlands, cause soil degradation, exacerbate water scarcity, and severely impact crop and animal production. The unpredictability of weather patterns also complicates essential farm planning, making planting and harvesting schedules more difficult and contributing to reduced yields.

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A critical mechanism by which climate change threatens food security is the disruption of ecological balance and the resultant alteration in the dynamics of crop pests and diseases. The intensification of extreme weather events, shifts in climatic regimes, and warmer winters are enabling pests and diseases to expand into new regions, complicating their prevention and control. These events—such as crop failures and crop pest outbreaks—threaten not only yield stability but also the resilience of cropping systems and the long-term viability of agricultural livelihoods (Eftekhari, 2022). The Food and Agriculture Organization (FAO) further reports that climate change is intensifying the spread and destructiveness of plant pests, which already destroy up to 40% of global crops annually (IPPC Secretariat, 2021). Therefore, a comprehensive understanding of these multidimensional impacts is vital for developing the adaptive measures and innovative solutions necessary to build a more resilient and sustainable global food system.

1.2 Definition of Climate Smart Cropping Systems

Climate Smart Cropping Systems refer to an integrated set of practices and technologies designed to sustainably increase crop productivity, enhance resilience to climate variability, and reduce or remove greenhouse gas emissions from cropping systems (FAO, 2013, Zheng *et al.*, 2024). These systems are especially vital for smallholder farmers and agricultural stakeholders in vulnerable regions, where climate change poses serious threats to food security and livelihoods.

The concept of CSCS emerged from the broader Climate Smart Agriculture (CSA) framework which was articulated by the Food and Agricultural Organization (FAO), at the 2010 Hague Conference on Agriculture, Food Security and Climate Change (FAO, 2010).

The CSCS concept focus specifically on crop production, and has the following key features (Bhattacharyya *et al.*, 2020; Danquah *et al.*, 2025):

- Use of Climate-Adapted Seeds: High-quality seeds tailored to local climate conditions and pest resistance.
- Crop Diversification: Growing a variety of crops to reduce risk and improve soil health.
- Sustainable Mechanization: Employing tools and machinery that minimize environmental impact.

- Soil and Water Conservation: Practices like mulching, contour farming, and cover cropping to preserve resources.
- Improved Water Management: Efficient irrigation systems and rainwater harvesting to cope with water scarcity.
- Knowledge Transfer: Training and support for farmers to adopt climate-resilient techniques.

The goals of CSCS are similar to the “three pillars” of climate smart agriculture (van Wijk et al., 2020). These goals are often referred to as the “triple wins” of CSA, and they form the backbone of CSCS strategies. They are:

- Productivity: Increase yields and farm profitability without degrading natural resources.
- Adaptation: Help farmers cope with climate variability and extreme weather events.
- Mitigation: Reduce emissions from agriculture and enhance carbon sequestration.

1.3 Principles Guiding Climate Smart Cropping Systems

Climate-smart cropping systems are built on a set of guiding principles. The guiding principles aim to make agriculture more resilient, productive, and environmentally sustainable in the face of climate change (Bhattacharyya *et al.*, 2020). These principles ensure that farming practices not only adapt to changing conditions but also contribute to climate mitigation and long-term food security (Agric4Profits, 2024). These principles form the foundation for transforming traditional agriculture into a climate-smart future.

The key principles include:

- Sustainable Resource Use: Maximize efficiency in water, nutrients, and energy use, and promote conservation of soil, water, and biodiversity.
- Resilience Building: Enhance the ability of crops and farming systems to withstand climate shocks like droughts, floods, and heatwaves. As well as the use of climate-resilient crop varieties and diversification of cropping systems.
- Environmental Protection: Reduce greenhouse gas emissions from farming activities, and avoid practices that degrade natural ecosystems or contribute to climate change.
- Integrated Soil and Water Management: Apply techniques like rainwater harvesting, drip irrigation, and cover cropping to maintain soil health and optimize water use.
- Biodiversity Enhancement: Encourage intercropping, agroforestry, and crop rotation to support ecosystem services and reduce pest/disease risks.

- Knowledge and Capacity Building: Invest in farmer education, extension services, and access to climate-smart technologies. Promote participatory approaches that involve local communities in decision-making.
- Profitability and Livelihood Support: Ensure that climate-smart practices are economically viable for farmers, and improve access to inputs, credit, and markets to support adoption.
- Social Inclusion and Equity: Embed gender equality, disability inclusion, and support for marginalized groups in all CSA activities.
- Anticipatory Risk Management: Integrate early warning systems and climate forecasting into farm planning.
- Systems Thinking: Consider the entire agricultural landscape, including policy, labor, and ecological interactions, when designing cropping systems.
- Context-Specific Solutions: Tailor practices to local environmental, economic, and cultural conditions.
- Knowledge Integration: Combine indigenous knowledge with modern scientific innovations.

1.4 Importance for Environmental Sustainability

CSCS practices are essential for achieving environmental sustainability, as they integrate agricultural productivity with ecological preservation and climate resilience (Amon, 2023). These systems help conserve natural resources by reducing the overuse of water, soil, and nutrients through methods like precision farming and conservation agriculture (Branson, 2011). They also play a significant role in mitigating climate change by lowering greenhouse gas emissions from fertilizers, machinery, and land-use changes, while promoting carbon sequestration through practices such as agroforestry and cover cropping (Parvej *et al.*, 2025).

Water efficiency is another critical benefit, with techniques like drip irrigation and the use of drought-resistant crops helping to minimize water waste and protect aquatic ecosystems (FAO, 2024; Soujanya and Gurjar, 2024). By encouraging crop diversification and integrated pest management, climate-smart systems support biodiversity, reducing the need for harmful chemical inputs that threaten wildlife and soil health (Chellam *et al.*, 2024; Bishnu Angon *et al.*, 2023). Additionally, they promote waste reduction through composting and recycling of organic matter, which not only enriches the soil but also prevents agricultural runoff and pollution (Moktadir, 2024; TGED Foundation, 2025).

These systems also enhance resilience to climate extremes that have become common occurrences due to climate change—such as floods, droughts, and heatwaves—ensuring long-term food security without compromising environmental integrity (Akinkuolie *et al.*, 2025; CS-SUNN, 2025). By fostering a circular economy, they encourage the reuse of agricultural by-products and the integration of livestock and crop systems, reducing reliance on external inputs and creating self-sustaining farms (Amon, 2023; UNCRD, 2024). Ultimately, climate-smart cropping systems represent a holistic approach to farming that safeguards the environment while meeting the growing demands of food production in a changing climate.

1.5 Global Support and Policy Frameworks for Climate-Smart Cropping Systems

Global frameworks and initiatives create a robust ecosystem for scaling climate-smart cropping systems, ensuring that agricultural transformation is both environmentally sustainable and socially inclusive (FAO, 2023; UNFCCC, 2024).

Global support and policy frameworks are instrumental in advancing environmental sustainability through climate-smart cropping systems (CSCS). These frameworks provide the strategic direction, funding mechanisms, and institutional backing necessary to scale sustainable agricultural practices worldwide (World Bank, 2023). Central to this effort is the 2030 Agenda for Sustainable Development, which outlines 17 Sustainable Development Goals (SDGs) that emphasize responsible consumption, climate action, and life on land (UN DESA, 2015). Complementing this is the Paris Agreement, which commits nations to reduce greenhouse gas emissions and adapt to climate change through nationally determined contributions (UNFCCC, 2024). The Sendai Framework for Disaster Risk Reduction also plays a role by promoting resilience against climate-related disasters (UNDRR, 2015).

In addition to these overarching frameworks, targeted global initiatives have emerged to support the scaling of CSCS. The FAO's Climate-Smart Agriculture (CSA) program is a leading example, offering technical guidance, policy support, and investment tools to help countries transform their agri-food systems toward sustainability (FAO, 2023). The United Nations Framework Convention on Climate Change (UNFCCC) integrates CSA into its climate strategies, emphasizing its role in reducing emissions, enhancing resilience, and securing food systems (UNFCCC, 2024). Meanwhile, the African Climate-Smart

Agriculture Alliance (ACSAA) works to promote CSA adoption across the continent, aiming to reach millions of smallholder farmers through coordinated efforts among governments, NGOs, and research institutions (AUDA-NEPAD, 2019).

These initiatives foster enabling policy environments and mobilize funding to support CSA implementation. National adaptation plans and donor-funded projects further enhance adoption by providing technical assistance, infrastructure investment, and capacity-building (CGIAR, 2015). For instance, the ACSAA aligns with the African Union's Vision 25x25, which seeks to scale CSA practices to 25 million farm households by 2025 (AUDA-NEPAD, 2019). Such efforts are supported by regional economic communities and national agricultural investment plans, ensuring that CSA is embedded in broader development strategies (FAO, 2017).

2.0 Practical Applications of Climate Smart Cropping Systems

As have been mentioned above, Climate Smart Cropping Systems (CSCS) provide a pragmatic response to the growing challenges of climate variability, declining soil fertility, and increasing food insecurity. By integrating climate-resilient practices into crop production, CSCS enables farmers to sustainably increase yields, adapt to changing climatic conditions, and contribute to environmental conservation. These systems are not merely theoretical frameworks; they are being implemented on farms, in communities, and across landscapes with measurable benefits.

The practical applications of CSCS span a wide spectrum of agroecological and socio-economic contexts. From the use of drought-tolerant crop varieties and conservation tillage in the Sahelian zones, to precision agriculture technologies and agroforestry in more humid and highland regions, these systems demonstrate versatility and scalability. They often build on indigenous knowledge and locally available resources, making them accessible and cost-effective for smallholder farmers. Moreover, they align with broader development goals by enhancing livelihoods, reducing emissions, and safeguarding natural ecosystems.

A range of practices that form the foundation of climate-smart cropping systems are discussed below. These practices enhance productivity while improving resilience to

climate variability and contributing to greenhouse gas mitigation. Each of them addresses a distinct pillar of sustainable crop production in the face of climate change.

2.1 Conservation Agriculture and its Role in Climate Smart Cropping Systems

Conservation agriculture is also known as regenerative agriculture and is different from conventional or traditional tillage-based farming systems. Conservation Agriculture and its Role in Climate Smart Cropping Systems Conservation agriculture (CA) is a proven climate-smart approach built on three interrelated principles—minimum soil disturbance, permanent soil cover, and crop diversification (Thierfelder et al., 2017). By limiting tillage, CA preserves soil structure and organic matter, reducing erosion and carbon emissions. The use of crop residues and cover crops enhances soil moisture retention, mitigates temperature fluctuations, and suppresses weed growth.

In climate-smart cropping systems, CA enables long-term productivity by improving soil health, reducing vulnerability to drought, and promoting carbon sequestration (FAO, 2023). Smallholder farmers in Nigeria have increasingly adopted CA with support from NGOs and research institutions, particularly in dryland areas where moisture conservation is critical.

2.2 Sustainable Crop Rotations and Intercropping Strategies

Crop rotation and intercropping are central to enhancing resilience in cropping systems. Rotating cereals with legumes improves soil fertility through biological nitrogen fixation and disrupts pest and disease cycles (The Farming Insider, 2024). Intercropping—particularly legume-based systems—maximizes land use efficiency and ensures more stable yields under erratic rainfall (Weih *et al.*, 2022).

These practices contribute to climate-smart outcomes by reducing dependence on external inputs, enhancing biodiversity, and improving household nutrition and income. In Northern Nigeria, maize-cowpea rotations and millet-groundnut intercropping are common practices that align with CSA principles.

2.3 Precision Agriculture and Digital Farming for Climate Resilience

As mentioned above, Climate Smart Cropping Systems (CSCS) provide a pragmatic response to the growing challenges of climate variability, declining soil fertility, and

increasing food insecurity (FAO, 2023; Roy and George, 2020). By integrating climate-resilient practices into crop production, CSCS enables farmers to sustainably increase yields, adapt to changing climatic conditions, and contribute to environmental conservation. These systems are not merely theoretical frameworks; they are being implemented on farms, in communities, and across landscapes with measurable benefits (CGIAR, 2022).

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A range of practices that form the foundation of climate-smart cropping systems are discussed below. These practices enhance productivity while improving resilience to climate variability and contributing to greenhouse gas mitigation. Each of them addresses a distinct pillar of sustainable crop production in the face of climate change.

2.4 Agroforestry and its Integration with Cropping Systems

Agroforestry integrates trees with crops and/or livestock on the same land unit, contributing significantly to climate mitigation and adaptation (Dagar and Gupta, 2025). Trees act as windbreaks, reduce evapotranspiration, and enhance carbon storage. Leguminous trees like *Gliricidia sepium* and *Leucaena leucocephala* improve soil fertility and provide fodder or fuelwood.

In Nigerian contexts, parkland agroforestry systems, such as shea (*Vitellaria paradoxa*) and dawadawa trees (*Parkia biblobosa*) scattered on crop fields in the savanna, provide both environmental and economic benefits. Agroforestry strengthens CSCS by diversifying incomes, increasing ecological resilience, and protecting ecosystems.

2.5 Soil Conservation and Management for Climate Smart Cropping

Healthy soils are the cornerstone of climate-smart cropping systems. Practices such as composting, mulching, contour ploughing, terracing, and the use of organic amendments enhance soil structure, increase water retention, and sequester carbon (Bhattacharyya *et al.*, 2020). Integrated Soil Fertility Management (ISFM), which combines organic and inorganic nutrient sources, boosts both productivity and environmental health.

Soil degradation—particularly in northern and central Nigeria due to overgrazing, intensive farming, and deforestation—threatens agricultural sustainability. Addressing this challenge through targeted conservation measures is essential for building resilient cropping systems in diverse agroecological zones. This has informed government investment in land restoration projects such as the World Bank funded Agro Climatic Resilience in Semi Arid Landscapes (ACReSAL) project being implemented across the 19 northern states and of Nigeria, and the Federal Capital Territory (FCT) (ACReSAL, 2025).

Table 1. Summary of Practical Applications of Climate Smart Cropping Systems

Practice	Core Features	Climate-Smart Benefits
Conservation Agriculture	- Minimum or zero tillage - Permanent soil cover - Crop diversification	- Preserves soil structure - Enhances moisture retention - Sequesters carbon
Crop Rotation & Intercropping	- Rotating cereals with legumes - Mixed cropping systems	- Improves soil fertility - Disrupts pest cycles - Stabilizes yields
Precision Agriculture	- GPS-guided tools - Satellite imagery - Variable-rate input application	- Optimizes input use - Enhances yield predictability - Reduces waste
Agroforestry Integration	- Trees + crops/livestock on same land - Use of leguminous trees	- Provides shade & windbreaks - Improves soil fertility - Stores carbon

Practice	Core Features	Climate-Smart Benefits
Soil Conservation & Management	- Composting & mulching - Terracing & contour ploughing - ISFM practices	- Boosts water retention - Prevents erosion - Enhances long-term productivity

3.0 Climate Smart Cropping Systems in Different Environments of Nigeria

Nigeria's diverse ecological regions—from the arid savannas to the humid rainforests and floodplains—demand localized approaches to climate-smart cropping. Below, we explore how CSCS is adapted across these agroecological zones to address unique climate challenges and leverage local opportunities.

3.1 Climate Smart Cropping in the Savannas of Northern Nigeria

Northern Nigeria, characterized by semi-arid and dry sub-humid climates, is vulnerable to drought, desertification, and erratic rainfall. This region has also been characterised by localised overgrazing, intensive cropping and deforestation. Climate-smart cropping in this region focuses on drought-tolerant varieties (e.g., sorghum, millet), conservation agriculture, zai pits, tasa (modified zia pits), and water harvesting techniques (Gabriel *et al.*, 2023). Farmers adopt early-maturing legumes and integrate agroforestry species like *Faidherbia albida* to improve soil fertility and reduce wind erosion (HarvestPlus, 2024).

Innovations such as micro-dosing fertilizer—applying small, precise quantities directly to the planting hole—and dry planting techniques further enhance productivity under constrained moisture conditions. Development programs in Kano, Katsina, and Borno have demonstrated improved yields through these practices (Gabriel *et al.*, 2023).

3.2 Climate Smart Cropping in the Tropical Rainforests of Southern Nigeria

The southern rainforest zone experiences high rainfall and humidity but faces challenges like soil leaching, nutrient runoff, and increasing pest pressure. CSCS in this region emphasizes integrated pest management (IPM), agroforestry, composting, and mulching (Mbanasora *et al.*, 2024). Crops like cassava, plantain, cocoa, and oil palm are integrated with shade-tolerant legumes to enhance biodiversity and reduce disease risk (Onyeneke *et al.*, 2017).

In addition, climate-resilient cropping calendars and raised-bed systems mitigate flooding risks, while digital weather forecasting services support timely field operations (Mbanasora *et al.*, 2024).

3.3 Climate Smart Cropping in the Derived Savannas of Western Nigeria

This transitional zone between rainforest and guinea savanna is a prime area for mixed cropping systems. Farmers grow maize, cassava, and yam, often in complex intercropping arrangements with legume crops. Climate-smart strategies include rotation with legumes (e.g., cowpea, soybean), conservation tillage, and compost application (Adekoya *et al.*, 2023). No-till systems for rice cultivation are being practiced in states like Benue, Kogi, and Nasarawa.

Climate-smart cropping practices are deployed at state and local government levels and within community contexts. For instance, Oyo, Osun, and Ogun States have focused on promoting CSA through farmer field schools, which train rural households on best practices for soil and water management. Adoption of agroforestry species and erosion control structures is also increasing (Adekoya *et al.*, 2023).

3.4 Climate Smart Cropping in the Montane Regions of Nigeria

Montane areas in Nigeria are high-altitude regions with unique vegetation and climate conditions. These areas include:

- Jos Plateau (Plateau State): Grasslands with forested slopes
- Obudu Plateau (Cross River State): Montane forests and grasslands
- Adamawa Highlands (Adamawa and Taraba States): Mountainous forests and plateaus
- Mambilla Plateau (Taraba State): Fertile volcanic soils and montane vegetation

These highlands have cooler climates and fertile soils but face soil erosion and deforestation due to population pressure. Climate-smart cropping here includes terracing, contour farming, and tree-based farming systems that prevent soil loss (NABG, 2025). Farmers cultivate Irish potatoes, vegetables, and grains using organic amendments and erosion barriers. Integration of perennial crops and agroecological practices is essential to sustaining productivity while conserving the unique montane ecosystems (Adekoya *et al.*, 2023).

3.5 Climate Smart Cropping in the Floodplains of the Niger Delta

The floodplains of the Niger Delta are increasingly affected by sea-level rise, saltwater intrusion, and prolonged flooding. Climate-smart cropping in this region focuses on floating gardens, flood-tolerant varieties (e.g., FARO rice), and raised-bed vegetable farming (Amadi, 2013). Farmers are adopting integrated rice-fish systems and rotational wet-season cropping to improve food security and household income.

Extension programs emphasize early warning systems and water control infrastructure to enhance adaptation to changing hydrological patterns (CPED, 2017). These practices help mitigate the impacts of climate variability while supporting sustainable livelihoods in vulnerable coastal communities.

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