

Climate-smart agriculture as an approach to sustainable food security: Opportunities and challenges

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Abstract: This study aims to highlight the importance of climate-smart agriculture as a transformative approach that leverages technology and scientific data to enhance agricultural decision-making, reduce the consumption of natural resources, and increase productivity in sustainable ways. It also provides practical tools to help farmers adapt to climate change by controlling resources, improving farming methods, and implementing accurate management systems for the agricultural environment. Thus, it is not just an alternative to traditional agriculture, but a modern strategy that contributes to strengthening the resilience of agricultural systems to climate change, thereby positively impacting food security and improving the country's development outcomes in all its dimensions, especially in light of the growing variety of environmental problems.

Keywords: Climate-smart agriculture, Food security, Climate change adaptation, Sustainable agriculture, Agri-tech innovation.

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1. Introduction

Today, the world is facing increasing challenges in securing food for its populations, due to multiple factors that overlap with each other, most notably climate change, which has become a direct threat to countries' ability to achieve food security. The global climate is experiencing significant shifts in weather patterns, including rising temperatures, changes in rainfall amounts and timing, increased rates of drought and flooding, and desertification. These changes lead to a decrease in crop productivity, a decline in land fertility, and an increase in the spread of agricultural pests and diseases, which negatively impact global agricultural production, particularly in countries that rely primarily on traditional farming methods. In light of these challenges, it has become necessary to seek innovative agricultural solutions that can adapt to climate change, ensure the sustainability of agricultural production, and mitigate risks to food security. Among the solutions that have gained increasing importance are climate-smart agriculture, which aims to improve the efficiency of agricultural production through the use of modern technologies and scientific innovations, such as innovative irrigation systems, big data, artificial intelligence, and remote sensing, as well as improving the exploitation of natural resources, such as water and soil, and developing agricultural varieties that are more resistant to harsh environmental conditions.

Climate-smart agriculture) has a wide range of actions and policies needed to transform and reorient agricultural systems to support and sustain food security in the context of climate change. To strengthen the capacity of farming communities to cope with and adapt to the effects of this change, the FAO is increasingly supportive of incorporating this concept into the orientations of agricultural sectors, including crop production, livestock, forestry, fisheries, and aquaculture, at all national, regional, and international levels. By adopting advanced technology, including information management and analysis systems, to make the best possible production decisions at the lowest costs, and automating agricultural

processes such as irrigation, as well as monitoring soil and crops, we can optimize our operations.

This study seeks to shed light on Problematic Implementing smart agriculture policies As innovative solutions that can ensure food self-sufficiency and sustainable agricultural development in the world, in the context of extrapolating the opportunities and challenges of popularizing machine learning and artificial intelligence techniques which Face Financial, cognitive, and structural challenges in its applications, which opens Research perspectives on the most effective ways to apply smart agriculture in local contexts Differentiated.

2. Climate-smart agriculture: A conceptual approach

With research and policy linkages between climate change and agriculture intertwined, "climate-smart agriculture" has emerged as a conceptual framework that seeks to develop agricultural systems to simultaneously enhance food security and rural livelihoods, while facilitating adaptation to climate change. This is reflected in the original FAO document (FAO, 2010), where climate-smart agriculture is defined as: "agriculture that sustainably increases productivity and resilience (adaptation), reduces/mitigates greenhouse gases and promotes the achievement of food security and national development goals." ¹

It has also been defined as: "an integrated approach aimed at addressing the challenges of climate change and achieving food security by sustainably improving agricultural production systems." This approach is based on the development of practices and techniques that enhance agricultural productivity, mitigate carbon emissions, and increase the resilience of farming communities to climate change.

Climate-smart agriculture is sometimes presented as a mechanism to achieve synergy between three main pillars, through which climate-smart agriculture has become known as a so-called "triple win", i.e., working simultaneously to achieve its three goals: "adaptation, mitigation, and food security". By linking a variety of disciplines in agricultural and environmental sciences, and using climate change science data and models by the agricultural research community, such as the Intergovernmental

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Panel on Climate Change (IPCC) projections, along with the organization of scientific data and related policies, will help further improve the concept of climate-smart agriculture.

The concept of climate-smart agriculture has its earliest beginnings in a 2009 report by the Food and Agriculture Organization of the United Nations (FAO) entitled "Food Security and Climate Change Mitigation in Developing Countries: Options for Synergies", which called for the integration of agriculture into climate policies as a sector affected by climate change while contributing to it.²

In 2010, the concept was formally presented through an FAO background paper at the Hague Conference on Agriculture, Food Security, and Climate Change, where three key pillars were emphasized: increasing agricultural productivity and income, enhancing climate change adaptation, and mitigating greenhouse gas emissions.³

This was followed in 2011 by a scientific report that reinforces evidence of the effectiveness of climate-smart agriculture practices in improving food security and reducing emissions, providing a strong knowledge foundation for the concept.⁴

In 2013, the FAO launched a comprehensive guide to climate-smart agriculture, serving as a key reference for practitioners and policymakers. This was followed in 2014 by the publication of the Global Research Agenda for Climate-Smart Agriculture (GSAA), which identified research priorities internationally.⁵

By 2015, the practical application of the concept had been expanded through regional workshops in the Asia Pacific, such as "Climate-Smart Agriculture: A Call to Action" in Bangkok.⁶

The 2016 initiatives focused on integrating them into small-scale farming systems through successful pilot projects in Africa, particularly in Kenya and Tanzania.⁷

Continuing this momentum, 2018 saw the release of an application booklet in collaboration with the African Development Bank, which

focused on translating the concept into practical and implementable investments in agricultural development projects.⁸

3. Objectives of climate-smart agriculture

Climate-smart agriculture involves a complex set of multiple goals and transformations, which include:

- **Adaptation to climate change:** by strengthening farmers' ability to cope with the effects of climate change, such as droughts, floods, and temperature changes.
- **Enhance agricultural productivity** by increasing food production to meet the growing needs of expanding populations.
- **Mitigating the effects of climate change:** reducing emissions from agricultural activities and enhancing carbon uptake in soils and plants.⁹

It is an integrative approach based on three pillars:

- **Economic:** Increase agricultural productivity sustainably, to support equitable increases in farm income, food security, and development.
- **Social:** Adaptation and building the capacity of agricultural and food security systems to adapt to climate change. Climate adaptation has been defined as the ability of ecological, social, or economic systems to cope with, recover from, and adapt to climate disruptions or shocks.
- **Environmental:** Reduce and eliminate greenhouse gas emissions from agriculture, because there are many opportunities to reduce the emission intensity of agricultural systems, that is, the amount of emissions per unit of product, without reducing or even increasing productivity.¹⁰

4. The importance of climate-smart agriculture

Climate-smart agriculture represents a vital solution to ensure the sustainability of agricultural production and meet global challenges related to climate and food security, as it includes the following objectives:

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- Support multisectoral action by coordinating efforts between farmers, researchers, the private sector, civil society, and policymakers and directing them towards resilient pathways to climate change through four primary areas of action: building evidence; increasing the effectiveness of local institutions; enhancing coherence between climate and agricultural policies; and linking climate to agricultural finance.
- Improve food security under climate change, so that climate-smart agriculture emphasizes agricultural systems that use ecosystem services to support productivity, adaptation, and mitigation." Including practices where these principles play a key role, such as crop diversification, overlapping farming, ecological rotation, agroforestry, biological disease surveillance, plant-animal interactions, and the use of agrobiodiversity.
- Reduce the negative environmental impact of agricultural activities.
- Strengthen the capacity of farmers, especially in developing countries, to adapt to the challenges of climate change.
- Support rural economic development through sustainable practices and work to improve farmers' incomes by increasing production efficiency.

5. Second Point: Climate-smart agriculture techniques

Climate-smart agriculture represents a set of strategies that enhance the resilience of agricultural systems by balancing priorities between a sustainable increase in agricultural productivity to enhance income levels and food security, climate change adaptation, and the sustainable resilience of natural agricultural system functions, and the reduction and elimination of greenhouse gas emissions that contribute to global warming.

Climate-smart agriculture embodied an agricultural system based on the application of advanced agricultural techniques in order to produce food in healthy ways, while preserving natural resources and rationalizing their

use: that is, sustaining these resources, increasing water use efficiency, reducing the costs of production inputs and maximizing the benefit from them through agricultural operations such as irrigation, fertilization, pest control, soil and crop monitoring, obtaining, analyzing and managing accurate data, and investing this data in directing agriculture accurately towards greater production at a lower cost, and to make appropriate decisions in Agricultural production process.¹¹

5.1. Soil management techniques

Soil management encompasses several key strategies aimed at enhancing soil fertility, preventing erosion, and promoting sustainability. These strategies include the following:

A. Enhancing soil fertility

- **Organic fertilizers:** The use of organic fertilizers, such as manure, to enrich soil fertility and improve its nutrient content.
- **Crop rotation:** Rotating different crop species each season to prevent nutrient depletion and improve soil structure.
- **Cover cropping:** Planting crops like beans and peas to fix nitrogen in the soil, thereby enhancing fertility.

B. Conservation tillage

- **Reduced tillage:** Minimizing tillage operations to prevent soil erosion and preserve soil health.
- **Contour farming:** Planting crops along the contours of the land to reduce erosion caused by rainfall and wind.¹²

5.2. Water management techniques

Effective water management is crucial for sustainable agriculture, particularly in regions prone to water scarcity. Key techniques include :

A. Water-conserving irrigation systems

- **Drip irrigation:** A method that delivers water directly to the roots of plants in precise quantities, reducing water waste.
- **Sprinkler irrigation:** The use of sprinkler systems to evenly distribute water over crops.

B. Rainwater harvesting

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- **Rainwater collection tanks:** Establishing tanks to collect and store rainwater for use during dry periods.
- **Agricultural terraces:** Constructing terraces to capture and retain rainwater, improve soil absorption, and reduce runoff.

C. Saline land reclamation

- Techniques for desalinating soil and using desalinated water for irrigation to restore soil health and enhance its agricultural potential.¹³

5.3. Smart crop management

Smart crop management involves utilizing innovative strategies and technologies to optimize crop production. This includes :

A. Development of Drought and Heat-Resistant Varieties

- Breeding crops that can withstand high temperatures and require less water, such as drought-resistant rice.

B. Multi-species agriculture

- **Intercropping:** Growing multiple crop species simultaneously to maximize positive interactions between plants, thereby enhancing overall productivity.
- **Agroforestry belts:** Planting trees to protect crops from wind and soil erosion, while promoting soil stabilization and carbon sequestration.

5.4. Digital technologies in agriculture

The integration of digital technologies can significantly enhance agricultural productivity and sustainability. Key technologies include:

A. Remote Sensing

- The use of satellites and drones to monitor crop health and soil conditions provides valuable data for decision-making.

B. Artificial intelligence and data analytics

- Leveraging AI and big data to analyze weather patterns, crop performance, and other relevant data to optimize agricultural practices.

C. Smartphone applications

- Applications are designed to assist farmers with planting schedules, irrigation timings, and pesticide management.

5.5. Smart livestock management

Innovative livestock management focuses on enhancing animal health, minimizing environmental impact, and maximizing productivity. Important practices include:

A. Improved feed

- Utilizing specialized feed that enhances livestock health and reduces methane emissions.

B. Manure management

- Managing manure effectively to produce organic fertilizers or biogas, reducing waste and emissions.¹⁴

C. Agricultural waste recycling

- Converting agricultural waste into organic fertilizers or bioenergy, thus reducing harmful emissions and improving sustainability.

5.6. Emission reduction techniques

Techniques to mitigate agricultural emissions are critical for combating climate change. These include:

A. Low-Carbon composting techniques

- Applying fertilizers in ways that minimize the release of nitrous oxide, a potent greenhouse gas.¹⁵

B. Agroforestry

- Integrating trees with crops to absorb carbon dioxide and promote carbon sequestration.

5.7. Risk management and agricultural insurance

Risk management is vital for safeguarding farmers against unpredictable weather patterns and climate-related disasters. The implementation of agricultural insurance systems can provide financial protection and enhance resilience to environmental challenges.

6. Third Point: Possible sustainability of food security: between the comparative advantages of smart agriculture and the limited application

Food security is one of the most prominent strategic issues that occupies a central position in the development policies of countries, due to its direct link to the lives of individuals and the stability of societies. Access to adequate and safe food is one of the fundamental human rights, and the continuity and quality of this food are among the most prominent indicators of a state's ability to cope with economic and environmental crises. Food security is critical in light of the increasing challenges posed by climate change, the growing global demand for food, and the shrinking availability of natural resources.

Despite conflicting opinions on the possibilities of developing the concept of climate-smart agriculture in light of the difficulty of negotiation tracks and political processes aimed at alleviating poverty, achieving food security, and mitigating the effects of climate change, which in turn reflect different interests and different stakeholders. However, there are a growing number of climate change plans and strategies that illustrate adaptation and mitigation of climate change impacts on agriculture and the food system at the national level. Policies have been developed to establish environmental and social safeguards for climate-smart agriculture, addressing a pressing issue by incorporating compliance indicators for climate-smart agriculture techniques and methods that are tailored to food sustainability requirements, which encompass the following elements.¹⁶

- **Productivity:** Climate-smart agriculture aims to increase agricultural productivity and incomes from crops, livestock, and fish in a sustainable manner, without creating a negative impact on the environment, thereby enhancing food security. The basic concept of raising productivity is sustainable intensification.
- **Adaptation or resilience:** climate-smart agriculture aims to reduce farmers' exposure to short-term risks while improving their adaptability and resilience to long-term shocks and pressures, as well

as special attention to ecosystems and the services they provide to farmers; these services are essential to maintain productivity and enhance humanity's ability to adapt to climate change.

- **Reducing emissions:** Climate-smart agriculture should help reduce and/or reduce greenhouse gas emissions where and when possible, this means reducing emissions per calorie or kilogram of food, fiber or fuel produced, avoiding deforestation, and managing soil and vegetation cover in a way that contributes to maximizing its efficiency and role as a carbon store and absorbing carbon dioxide from the atmosphere.

Despite the promise of climate-smart agriculture to address climate change and achieve sustainable food security, the process of implementing it on the ground still faces a set of complex challenges that hinder the dissemination of this approach in many countries, especially developing ones.

These challenges range from financial to inadequate funding and investments, and from structural and technical issues related to technological and digital infrastructure, to cognitive and human-related issues, including the lack of qualified competencies and training capabilities.

6.1. Financial challenges

- Financial challenges manifest themselves in several aspects. First, the cost of purchasing technological devices and equipment is very high. For example, the cost of an intelligent irrigation system or drones can be high, making them unavailable to many small farmers. Second, there are ongoing operation and maintenance costs for these technologies, which increase the financial burden on farmers. Third, the use of technology requires specialized training and qualifications, which adds to the cost of teaching farmers how to use these tools effectively.
- Advanced machines, IoT devices, drones, and artificial intelligence systems require significant capital investments.¹⁷
- The cost of investing in modern agricultural technology poses a significant challenge, particularly for small farmers who often lack

sufficient financial resources. Cutting-edge agriculture relies on the use of technologies such as drones, advanced sensors, and artificial intelligence, each of which requires substantial investments. This initial investment can be an obstacle to technology adoption, and increase the gap between small and large farmers.¹⁸

To overcome these financial challenges, farmers can resort to some possible solutions. One such solution is agricultural cooperation, where a group of farmers can participate in the purchase and use of technology, reducing the individual cost. Additionally, governments and nonprofits can offer financial support and training to farmers, thereby enhancing their ability to adopt the technology. Small farmers can also benefit from concessional agricultural loans provided by banks and financial institutions to support investment in technology.

Thus, despite the significant financial challenges farmers face in adopting agricultural technology, there are multiple ways to overcome these obstacles. By leveraging cooperation and financial support, farmers can enhance their ability to utilize modern technology and reap its multiple benefits.¹⁹

6.2. Infrastructure challenges (Internet, digital terrestrial)

Smart agriculture produces vast amounts of data, and managing this data can be complicated. Farmers need systems to store, analyze, and interpret data effectively. Additionally, concerns exist about data privacy, particularly when sensitive farm data is shared with third parties.

Additionally, many rural areas, particularly in developing regions, lack the necessary infrastructure to support the implementation of innovative farming technologies. A lack of access to reliable internet, electricity, and other essential services can hinder the adoption of advanced technologies.

On the other hand, innovative agriculture technologies collect and store large amounts of data, which raises concerns about their security and

the confidentiality of agricultural information, especially in the absence of advanced protection systems or clear legislation.²⁰

With the advancement of technology and the adoption of big data in agriculture, new security challenges arise related to the protection of this data. Agricultural data is a valuable asset, as it contains sensitive information about crops, soil, and farming methods employed. This data can be a target of hacking or unauthorized use, putting farmers and agricultural businesses in a vulnerable position.

One of the main challenges is securing data from cyber-attacks, which can target agricultural systems to obtain valuable information that may be used for illicit purposes. Therefore, it becomes necessary to adopt strong cyber security strategies that include data encryption and the implementation of advanced firewalls.

This requires farmers and agricultural companies to use up-to-date software to avoid security vulnerabilities. Continuous software updates help fill the gaps that hackers can exploit to access sensitive data. Agricultural workers should also be trained in digital security best practices, including identifying fraudulent emails and avoiding the use of weak passwords.

Moreover, security challenges can arise from the use of IoT devices in the agricultural sector. These devices, such as sensors and drones, collect vast amounts of data that must be secured to protect privacy and intellectual property. It is essential to ensure that strong passwords protect these devices and are regularly updated.

Ultimately, securing agricultural data requires a joint effort from all stakeholders, including farmers, tech companies, and governments. Cooperation in the development and application of best security practices can help protect agricultural data from various security threats, ensuring the continuity and effectiveness of agricultural operations in the digital age.

6.3. Knowledge and training challenges: For expert human resources

Adopting smart agriculture requires a certain level of technical expertise, which can be a challenge for farmers unfamiliar with digital technologies. Training and education are crucial in bridging this gap and enabling farmers to utilize the tools at their disposal effectively.

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- **Integration and compatibility issue**

Another challenge is to integrate new innovative farming techniques with existing farming practices. Many farmers are already using traditional tools and methods, and moving to more automated and data-driven systems can be daunting.

- **Limited availability of skills**

Advanced technologies require trained labor, engineers, and specialized technicians, which many countries lack, especially in rural areas.

- **General Admission**

Some farmers and communities may be reluctant to adopt smart agriculture due to concerns about losing traditional jobs or its potential impact on the environment and societal balance, which necessitates extensive awareness efforts.

7. Fourth Point: Smart agriculture applications in the” UNITED ARAB EMERATES” model

The UAE has achieved significant achievements in developing the agriculture sector, and transforming the desert into green spaces and productive farms. Over the past decades, the area of agricultural land has changed 33 times, It also worked on qualitative agricultural experiments and adopted modern highly efficient technologies in agriculture Using smart systems for irrigation, fertilization and controlling water quality , it also allocates Financial incentives to agricultural technology companies seeking to establish or develop their businesses in the country, with the aim of enhancing the capabilities and innovations of modern agricultural technologies.²¹

The UAE is the first country in the Arab region to move towards smart agriculture, with the aim of meeting needs and achieving sustainability in agricultural production, it has made great strides in adopting smart agriculture as part of the policy of food diversity and optimal use of resources, and building the capacity to adapt to harsh weather conditions such as desertification, high temperatures, high humidity and the lack of water. It has made great progress in providing food

in modern and innovative ways, surpassing many advanced countries in this field. It works to make benefit from artificial intelligence in the field of agriculture and crop production, enabling her to use nature to overcome soil quality through the application of food technology.

The most important aspects of smart agriculture in the United Arab Emirates are as follows:

- **Robotic farms:**

These robots are used in the form of large aquariums planted with all kinds of edible plants, The machine learning software that operates the robot identifies plants showing signs of pests or diseases and removes them before they spread throughout the entire garden.

- **Smart Agriculture and the Internet of Things:**

The” Internet of Things” is one of the most important technologies used in smart agriculture, it is done by connecting one device to another via the Internet, and All smart devices, including mobile phones and home devices, as well as machines used in agricultural fields, so that it can be operated, controlled, and send and receive data from it via the Internet.

7.1. Evaluation of smart agriculture in the UAE between cost and economic return.

The establishment of infrastructure such as greenhouses (greenhouses) Vertical farming, Hydroponic systems, Refrigeration equipment, Industrial lighting (LED), and climate control systems. All of these applications require a large investment in equipment, construction and technology. In addition to the costs of importing technology, Training costs, consulting and accreditation technology(certification), However, from an economic perspective, the importance of climate-smart agriculture lies in its ability to generate tangible financial returns and viable growth opportunities in the medium and long term, whether for individual farmers or for the UAE national economy, it works to:

- **Increased productivity and yield:** Thanks to the use of technologies such as protected agriculture, hydroponics, drip irrigation, and digital applications for climate control and climate forecasting, Farmers can achieve higher yields and better crop

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quality. This means increased saleable quantity and improved price thanks to quality.

- **Reducing operational costs and resources:** Smart agriculture techniques help reducing water consumption (especially in the UAE where water scarcity is a government priority) by using technologies such as drip irrigation, water reuse, and managed water desalination. Also, better control of energy consumption (for example, using automation, smart lighting and cooling control), which reduces the operating bill.
- **Economic stability and risk reduction:** Smart agriculture increases farmers' ability to adapt to sudden climate changes (high temperatures, the lack of water, dust storms). This reduces damages that may occur as a result of climate crises, enhancing farmers' financial sustainability and stabilizing income.
- **Opening new investment and commercial opportunities:** Startups companies in vertical farming and smart agriculture have significant opportunities to attract huge capitals; an example of this is the vertical farming project in the UAE, in partnership with international companies. In addition to government policies and incentives that support these trends, such as supporting research and development, stimulating innovation, and issuing legislation that encourages efficient water and energy consumption.

Item	Approved indicators of success	Approved success indicators to achieve returns	Risk sensitivity
The initial investment is high, but if used efficiently, the cost can be recovered	Annual yield depends on crop type, climate control quality, local prices and operating costs.	Higher productivity, lower usage, better quality and competitive prices for high-	Risks such as rising energy costs, price fluctuations, failures in technical

within 37 years in smart agricultural projects such as vertical farming and protected agriculture, depending on the size of the project.		value crops (food quality, organic, local).	systems, plant epidemics, changes in policies or government support.
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Table1: smart agriculture between cost and economic return.

The table was prepared by the researcher

8. Conclusion

Climate-smart agriculture is an important strategy to face the challenges of climate change and ensuring global food security by adopting sustainable technologies and practices, so that farming communities can adapt to changing climatic conditions and enhance productivity in a manner that preserves the environment and ensures the long-term sustainability of natural resources.

Some climate practices may be smart in a specific local context, but they are not in other contexts, due to agro-ecological conditions, market opportunities, and stakeholder priorities. Thus, climate-smart agriculture practices necessitate the integration of multiple disciplines, and the simultaneous achievement of the three pillars of climate-smart agriculture underscores, the need for efforts among governments, farmers, and international organizations to support innovation and the adoption of innovative solutions worldwide. On this basis, work must be done to:

- The need to integrate climate-smart agriculture officially into national agricultural policies, while providing financial and technical support for its projects.

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- create training programs targeting farmers and agricultural professionals in the field of innovative technologies and sustainable climate practices.
- Improving digital infrastructure in rural areas is a cornerstone for the adoption of these agricultural models.
- Encouraging applied scientific research in the field of smart agriculture locally and linking it to national climate and environmental challenges.

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