Journal of contemporary economic research **ISSN 2623-2602/ EISSN: 2716-8891**
Vol 09 , N°: 2 **(20**26**), p** 181-202

Smart Agriculture as an Approach to Developing Agriculture and Enhancing Food Security: Evidence from Arab Experiences

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Received: 8/1/2026 **Accepted**: 10/30/2026 **Published**: 11/4/2026

Abstract:

This study examines the role of smart agriculture in enhancing food security in Arab countries amid climate change and natural resource scarcity. It focuses on key smart agricultural technologies and their contribution to improving productivity and resource efficiency. Based on a review of relevant concepts and selected Arab experiences, the findings show that smart agriculture can increase agricultural productivity, optimize the use of natural resources, particularly water, and support sustainable food security. However, its adoption remains constrained by weak technological infrastructure and the high cost of modern technologies.

The study therefore recommends greater investment in smart agricultural technologies, improved digital infrastructure, stronger support for research and training, and enhanced Arab cooperation and knowledge exchange to promote sustainable agricultural development and food security

Keywords: Smart Agriculture, Food Security, Modern Agricultural Technologies, Sustainable Agricultural Development, Arab Countries.

JEL Classification Codes : Q16, Q18, Q54, O33

1. INTRODUCTION

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Over the past few decades, the world has witnessed profound transformations across various economic sectors, driven by rapid technological advancement and increasing environmental challenges, particularly climate change and rapid population growth. The agricultural sector has been among the most affected, given its heavy dependence on natural resources such as land, water, and climate. In response to these challenges, there has been a growing need to adopt innovative agricultural approaches capable of improving productivity while ensuring long-term sustainability. Among these approaches, climate-smart agriculture (CSA) has emerged as one of the most promising solutions.

Climate-smart agriculture integrates advanced digital technologies, including artificial intelligence (AI), the Internet of Things (IoT), unmanned aerial vehicles (UAVs), and sensor-based systems, to optimize resource management, increase agricultural productivity, reduce production costs, and enhance the resilience of farming systems to climate change. At the same time, **food security** remains one of the most pressing challenges worldwide, particularly in the Arab region, where many countries face limited water resources, low agricultural productivity, and a high dependence on food imports. Consequently, the adoption of smart agriculture has become a strategic priority for strengthening agricultural resilience and achieving sustainable food security.

Research Problem:

Based on the above, the main research question of this study is:

To what extent can smart agriculture contribute to achieving food security in the face of the climatic and economic challenges affecting the agricultural sector?

Research Questions:

To address this question, the study seeks to answer the following sub-questions:

- What is the relationship between smart agriculture and food security?
- What is the current status of smart agriculture implementation in Arab countries?
- What are the major challenges limiting the adoption of smart agriculture in Arab countries, particularly in Algeria?

Significance of the Study:

This study is significant because it examines smart agriculture as an innovative solution to the challenges facing the agricultural sector, particularly those related to climate change and the scarcity of natural resources. It also highlights the role of modern agricultural technologies in improving agricultural productivity and strengthening food security. Furthermore, the study emphasizes the importance of accelerating the adoption of smart agriculture across Arab countries to support sustainable agricultural development.

Objectives of the Study

This study aims to:

-Examine the concept, characteristics, and key technologies of smart agriculture.

-Analyze the current status of smart agriculture implementation in selected Arab countries.

-Identify the major challenges to the adoption of smart agriculture and explore strategies for overcoming them to achieve sustainable food security.

Research Methodology

To address the research problem and answer the proposed questions, this study adopts the descriptive research approach. This method provides a comprehensive framework for examining the concepts, applications, and challenges of smart agriculture and assessing its role in enhancing sustainable food security.

2. Theoretical Framework of the Study Variable

2.1 Smart Agriculture:Smart agriculture is a relatively recent concept that has emerged in response to the growing challenges facing the agricultural sector, particularly climate change, the scarcity of natural resources, and the continuous increase in global food demand. It is based on the integration of digital technologies and technological innovations—such as artificial intelligence (AI), the Internet of Things (IoT), and remote sensing—to improve the efficiency of agricultural operations, increase productivity, and optimize the use of available resources. Consequently, smart agriculture has become one of the most important approaches to achieving sustainable agricultural development and strengthening food security. This highlights the need to examine its concept, key characteristics, and significance in advancing the agricultural sector.

2.1.1. Definition of Smart Agriculture: The term smart agriculture first emerged in 2009 and received its first official definition the following year during the Global Conference on Agriculture, Food Security and Climate Change held in The Hague. At this conference, the Climate-Smart Agriculture (CSA) initiative was launched under the leadership of the Food and Agriculture Organization of the United Nations (FAO), in collaboration with the World Bank. The initiative was designed to promote the adoption of agricultural systems, practices, and technologies tailored to the environmental, economic, and social conditions of different regions. Its primary objectives are to enhance the agricultural sector's capacity to adapt to climate change, strengthen its resilience to climate-related shocks, and contribute to the reduction of greenhouse gas emissions. In 2013, the FAO published the *Climate-Smart Agriculture Sourcebook*, a landmark
reference that further consolidated the concept by providing practical guidance on its implementation, with particular emphasis on supporting smallholder farmers and

vulnerable communities in developing countries (Muqaymah, Ramadan, & Harmoush, 2020, p. 186)

The World Bank defines climate-smart agriculture as "an integrated landscape management approach that addresses the interconnected challenges of food security and climate change" (Beltehat, 2024, p. 249)

In 2017, the United Nations General Assembly emphasized the importance of taking local conditions into account when implementing climate-smart agricultural practices, recognizing that environmental, economic, and social contexts vary across regions and over time. The adoption of this approach aims to generate multiple benefits, including increased agricultural productivity, enhanced resilience and adaptive capacity to climate change, and reduced environmental impacts. The General Assembly also highlighted the need to promote the use of modern agricultural technologies, such as crop insurance schemes, early warning systems, and weather forecasting services for agricultural production, as effective tools for reducing the risks faced by farmers. Furthermore, it called for expanding the application of agricultural biotechnology and strengthening research, development, and innovation efforts to improve agricultural productivity while supporting sustainable food security and nutrition. (Omar, Lakhal , & Abed, 2020, p. 208)

2..1.2. Importance and Benefits of Smart Agriculture:Smart agriculture offers several important benefits that contribute to the sustainability and efficiency of agricultural systems. Its main advantages include: (Souissi, 2023, p. 193)

-Improving the livelihoods of smallholder farmers by enhancing resource-use efficiency and promoting appropriate technologies for agricultural production, processing, and marketing.

-Reducing environmental degradation by encouraging sustainable farming practices that protect soil, air, and other natural resources.

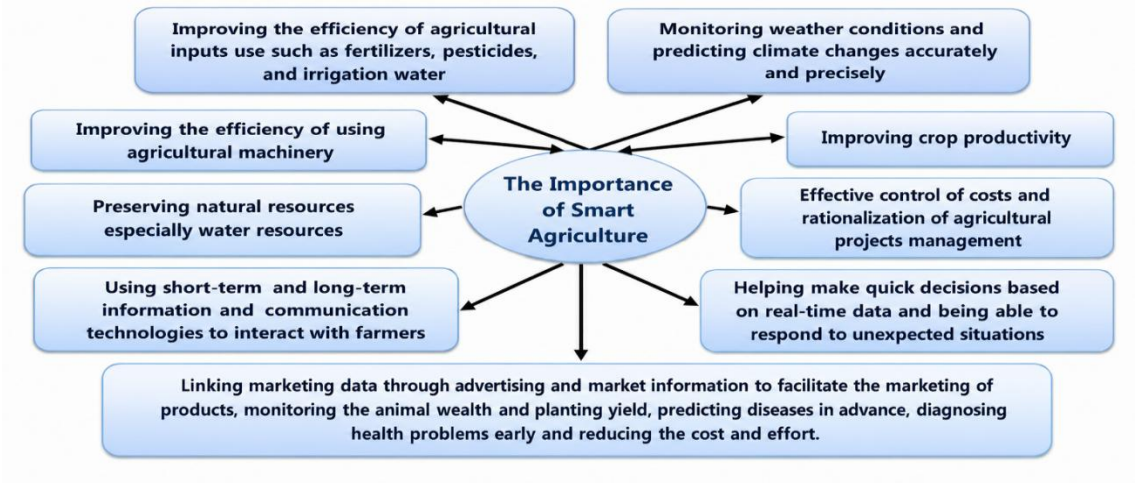
-Optimizing the use of natural resources while lowering dependence on fossil fuels and reducing greenhouse gas emissions.

-Supporting sustainable agricultural development by strengthening the resilience and adaptive capacity of farming systems to environmental and climate-related challenges.

-Lowering overall production costs through the adoption of advanced technologies, such as smart irrigation systems, which improve water and energy efficiency while increasing agricultural productivity.

Fig. 1. The Importance of Smart Agriculture

 ISSN 2623-2602/ EISSN: 2716-8891



Source : (Najah & Boukadir, 2025, p. 110)

Smart agriculture is widely recognized as one of the most effective approaches to addressing the challenges facing the agricultural sector. By integrating advanced technologies and digital innovations, it enhances production efficiency, increases productivity, strengthens food security, promotes the sustainable use of natural resources, and supports the production of safe, high-quality food. It also improves resilience to climate change, optimizes resource use, and reduces production costs.

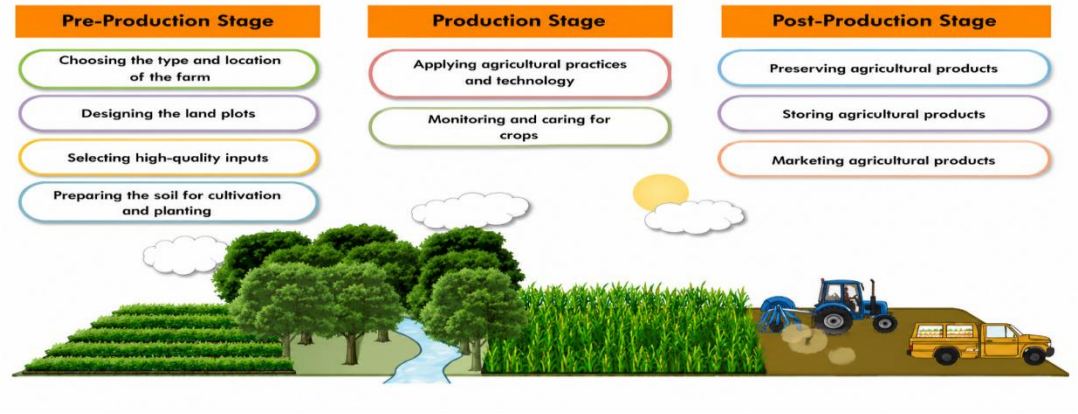
Despite these advantages, the agricultural sector continues to face significant constraints that limit its contribution to sustainable development and food security. These include limited agricultural resources, shrinking arable land due to desertification, water scarcity, and restricted agricultural expansion. Additional challenges involve low agricultural productivity caused by labor shortages, high levels of post-harvest losses and food waste, constraints in livestock production, weak agricultural research and extension services, limited adoption of modern technologies, and inefficiencies in agricultural marketing. (Sayari & Jebli, 2023, p. 32)

2.1.3. Technologies Used in Smart Agriculture:Smart agriculture relies on a range of digital technologies and technological innovations that distinguish it from conventional farming. These technologies improve farm management, optimize resource use, and enhance both agricultural productivity and crop quality. The most widely used technologies include the following:

2.1.3.1. Artificial Intelligence (AI):The growing availability of large, high-quality, and real-time data has increased the need for advanced computing technologies capable of processing big data and transforming it into actionable insights for agricultural decision-making. In this context, artificial intelligence (AI) has emerged as a key driver of agricultural innovation. Machine learning is already being applied in areas such as crop yield prediction, agricultural data analysis, and AI-powered advisory services through chatbots. As these technologies continue to evolve, their applications are expected to become more sophisticated, while augmented intelligence is increasingly recognized as

an effective approach for supporting decision-makers by combining human expertise with intelligent data analysis. (Soudani, 2022, p. 52)

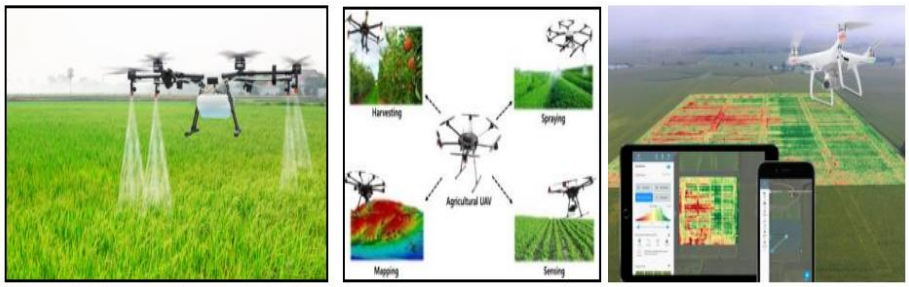
Fig. 2. Stages of Using Artificial Intelligence to Enhance Agricultural Production



Source : (Harfoush & Ben Atta Allah, 2024, p. 382)

2.1.3.2. Unmanned Aerial Vehicles (UAVs):Unmanned Aerial Vehicles (UAVs), commonly known as drones, are among the most important technologies used in smart agriculture. They enable efficient crop monitoring, field assessment, high-resolution aerial mapping, and the measurement of environmental indicators such as air quality. UAVs are also widely used for the precise application of pesticides and fertilizers, improving operational efficiency while reducing farmers' exposure to potential hazards. In addition, they collect and transmit real-time field data to specialized analytical systems, supporting more accurate and timely agricultural decision-making. As digital technologies continue to advance, the agricultural drone market is expected to expand significantly, driven by the growing adoption of smart farming solutions. (Al-Shami, Al-Huwaiti, & Askar, 2026, p. 150)

Fig. 3. Agricultural Drones (Unmanned Aerial Vehicles, UAVs)



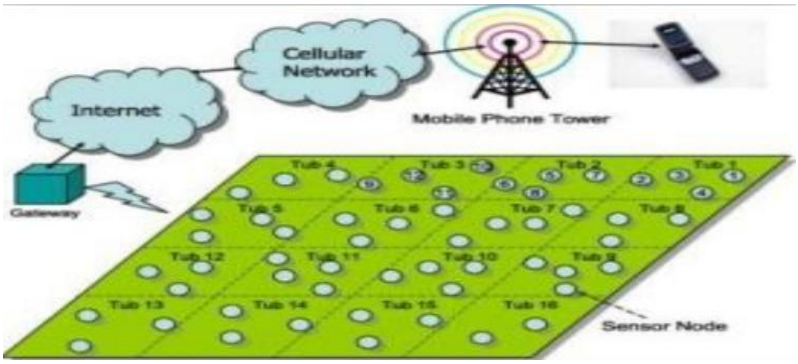
Source : (Sayari & Jebli, 2023, p. 36)

2.1.3.3. Sensors:Sensors play a fundamental role in smart agriculture, particularly in smart irrigation systems, where they continuously monitor crop water requirements with high precision. By supplying the right amount of water at the right time, these systems improve water-use efficiency and minimize resource wastage. In addition, sensor technologies enable the early detection of pests, diseases, and other crop-related issues,

 ISSN 2623-2602/ EISSN: 2716-8891

helping reduce yield losses while enhancing crop productivity, quality, and the overall sustainability of agricultural production. (Soudani, 2022, p. 469)

Fig. 4. Remote Sensing Devices



Source : (Sayari & Jebli, 2023, p. 40)

2.1.3.4. Agricultural Robotics:Agricultural robotics has advanced significantly in recent years, with the development of autonomous robots capable of performing a wide range of farming tasks efficiently. These robots rely on advanced technologies, including computer vision and deep learning, to analyze data collected from drones and smart devices, thereby improving the accuracy and efficiency of agricultural operations. Their increasing adoption is expected to reduce dependence on manual labor while enhancing productivity and operational efficiency. Notable applications include robots designed for harvesting, sorting, and packaging crops, enabling faster operations and lower production costs. (Harfoush & Ben Atta Allah, 2024, p. 34)

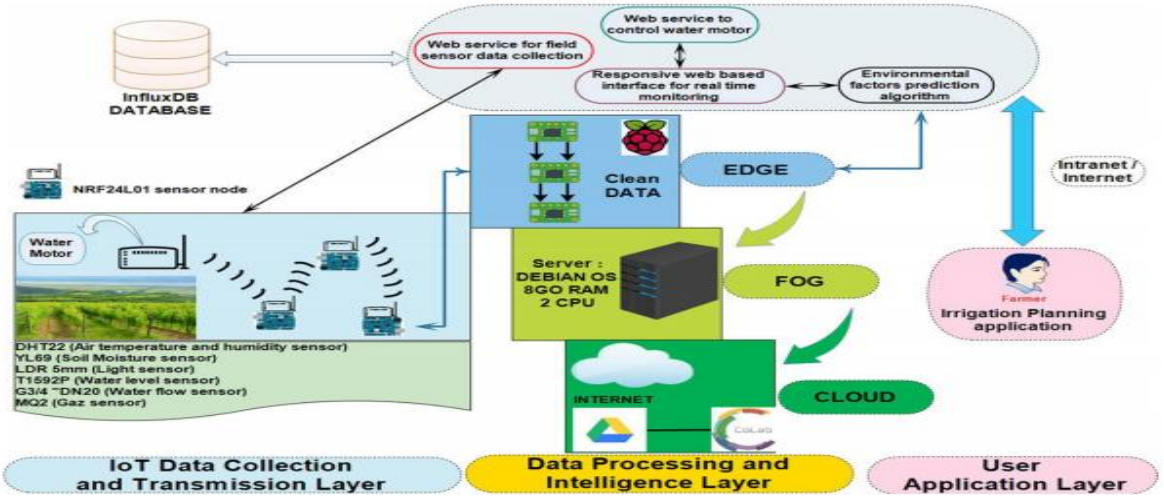
Fig. 5. Agricultural Robots



Source : (Debbouche & Biri, 2023, p. 146)

2.1.3.5. Internet of Things (IoT):The Internet of Things (IoT) is one of the key technologies driving the advancement of smart agriculture. It relies on interconnected sensors and devices that enable the real-time collection and analysis of agricultural data. This technology provides farmers with accurate information on soil conditions, moisture levels, temperature, wind speed, and other environmental parameters, allowing them to make more informed and timely decisions. By improving resource management, optimizing the use of water and fertilizers, and reducing waste, IoT contributes to higher agricultural productivity and better crop quality. (Najah & Boukadir, 2025, p. 118)

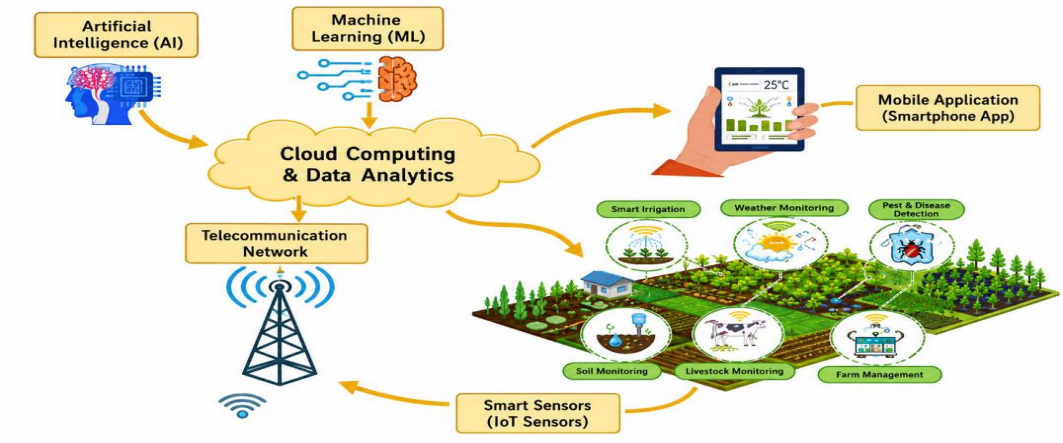
Fig. 6. Architecture of an IoT-Based Smart Agriculture System



Source : (Souissi, 2023, p. 195)

2.1.3.6. Blockchain Technology: Blockchain is an emerging technology that enhances transparency and traceability across agricultural and food supply chains. It enables the use of smart contracts and provides a secure system for tracking food products throughout the stages of production, transportation, and distribution. By ensuring the integrity and authenticity of product data, blockchain allows farmers, suppliers, retailers, and consumers to verify product origin and movement, strengthening trust among stakeholders while improving food safety, product quality, and supply chain efficiency. (Sayari & Jebli, 2023, p. 52)

Fig. 7. Applications of Smart Agriculture



Source : (Harfoush & Ben Atta Allah, 2024, p. 382)

2.2. Food Security: Conceptual Framework

2.2.1. Concept of Food Security:Food security has been defined in various ways by international organizations, reflecting different perspectives on the concept. The World Health Organization (WHO) defines food security as the set of conditions and standards

that must be maintained throughout the entire food chain—from production, processing, storage, transportation, and distribution to final preparation for consumption—to ensure that food is safe, wholesome, and suitable for human consumption. Accordingly, food security extends beyond the mere availability of food to encompass its safety and quality at every stage of the food supply chain until it reaches the final consumer. (Sammar, 2022, p. 445). According to the Food and Agriculture Organization of the United Nations (FAO), food security exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. This definition emphasizes that food security extends beyond food availability to include accessibility, food quality and safety, and the continuous availability of adequate food to meet nutritional needs in a sustainable manner. (Mokaddam & Fares, 2023, p. 52). Food security is built upon several fundamental characteristics that ensure its effectiveness and long-term sustainability. These include: (Bouabdelli & Gharbi, 2023, p. 313)

–Availability: Ensuring an adequate food supply through domestic production, strategic reserves, or imports to meet the nutritional needs of the population.

–Independence: Reducing excessive reliance on external markets, thereby limiting the impact of global market fluctuations and political or economic disruptions on food supplies.

–Stability: Maintaining a reliable food supply and continuous access to food throughout the year, while minimizing seasonal and economic fluctuations.

–Sustainability: Conserving natural resources and ecosystems to ensure the long-term capacity to produce sufficient food for present and future generations.

–Equity: Guaranteeing that all members of society have equal access to sufficient, safe, and nutritious food without discrimination.

2.2.2. Types of Food Security:Food security can be classified into three main types, depending on the degree of reliance on domestic production and the sustainability of food supply: (Hajjaj, 2025, p. 68)

–Relative Food Security: Refers to a country's ability to meet the basic food needs of its population through a combination of domestic production and imports, without requiring complete self-sufficiency. The emphasis is on ensuring food availability and accessibility.

–Absolute Food Security: Describes a country's capacity to produce enough food domestically to satisfy, or even exceed, national demand. This form is closely associated with food self-sufficiency and a high level of reliance on domestic production.

–Sustainable Food Security: Focuses on maintaining a long-term balance between food availability and the sustainable management of natural resources. It aims to meet

the food needs of present and future generations while preserving the economic, social, and environmental sustainability of the food system.

2.3. The Relationship Between Climate-Smart Agriculture and Food Security

Climate change and food security are closely interconnected, as climate-related risks directly affect agricultural production, natural resources, and the stability of food systems. Rising temperatures, changing rainfall patterns, and the increasing frequency of extreme weather events reduce agricultural productivity and threaten the availability of food at both the national and global levels. In this context, the Food and Agriculture Organization (FAO) identifies four key dimensions of food security: (Moussa, Gumman, & Ilimi, 2022, p. 363)

−Food Availability: Ensuring an adequate supply of quality food through domestic production or imports to meet population needs.

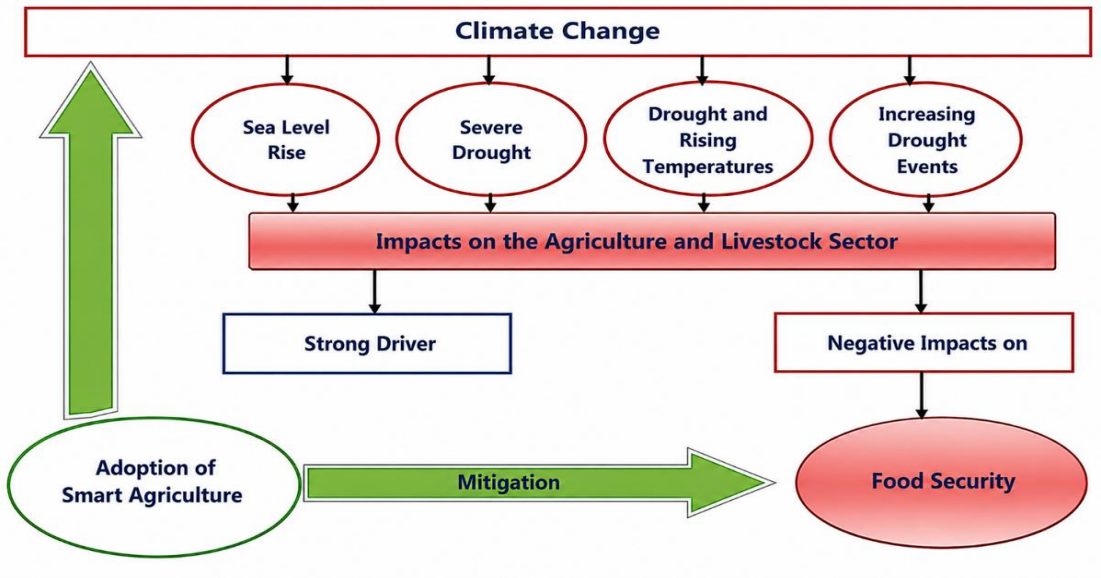
−Food Access: Ensuring that individuals have the economic and physical means to obtain sufficient, safe, and nutritious food.

−Food Utilization: Promoting the effective use of food through balanced diets, safe drinking water, adequate sanitation, and quality healthcare to achieve proper nutrition and good health.

−Food Stability: Ensuring that food remains consistently available and accessible over time, despite economic shocks, natural disasters, or seasonal fluctuations.

In regions highly vulnerable to climate change, farmers are increasingly adapting and transforming their farming systems to strengthen food security under changing climatic conditions. Climate-smart agriculture aims to enhance the resilience of agricultural systems and rural livelihoods while reducing the risk of food insecurity both now and in the future. This approach promotes sustainable farming practices such as conservation tillage, the use of drought-tolerant crop varieties, and crop rotation and diversification, enabling farmers to produce food more sustainably. (Moussa, Gumman, & Ilimi, 2022, p. 364)

Fig0 8. The Role of Climate-Smart Agriculture in Mitigating Climate Change Impacts and Achieving Sustainable Food Security



Source : (Chaa & Hadri, 2023, p. 226)

Investment in smart agriculture plays a vital role in strengthening long-term food security through several key contributions: (Bouthelja, 2022, p. 216)

–Creating new employment opportunities by promoting the adoption of smart farming technologies and encouraging entrepreneurship, innovation, and agricultural investment.

–Enhancing the sustainability of fisheries and aquaculture through climate-resilient technologies and improved management systems.

–Improving climate resilience by enabling agricultural systems to adapt to climate change while reducing greenhouse gas emissions through more efficient and sustainable resource use.

–Reducing poverty and hunger by increasing agricultural productivity, improving crop quality, minimizing losses, and raising farmers' incomes.

–Attracting agricultural investment by providing a technology-driven and climate-resilient environment that supports innovative and sustainable agricultural projects, particularly in arid and semi-arid regions.

3. Applied Framework of the Study

3.1. Smart Agriculture in the Arab World:In recent years, Arab countries have shown growing interest in adopting smart agriculture as an effective approach to addressing major agricultural challenges, particularly water scarcity, climate change, and the limited availability of arable land. Many countries in the region have increasingly integrated digital technologies and innovative solutions to improve agricultural productivity and strengthen food security. Accordingly, this section examines the current state of smart agriculture in the Arab world, highlighting key initiatives and successful experiences implemented by selected Arab countries.

3.1.1. The Importance of Investing in Smart Agriculture in Arab Countries

The Arab region has a pressing need to adopt smart agriculture in order to address the growing challenges facing its agricultural sector. The integration of digital technologies into agricultural development is essential for improving the management of natural, water, and human resources. Modern agricultural technologies also promote collaboration between Arab research institutions and international agricultural research centers, facilitating the transfer of innovative solutions that enhance agricultural development. Furthermore, smart agriculture helps reduce production costs, increase food productivity, strengthen food security, and address critical challenges such as water scarcity, soil salinity, limited arable land, and arid climatic conditions. It also contributes to the efficient and sustainable use of natural resources, particularly water. The importance of smart agriculture in the Arab world can be summarized as follows: (Khalid & Khalid, 2024, p. 167)

-Promoting Sustainable Agriculture: Smart agriculture supports sustainable farming by adopting advanced technologies that balance higher agricultural productivity with the conservation of natural resources, ensuring the long-term sustainability of agricultural production while meeting the needs of present and future generations.

-Conserving Natural Resources and Enhancing Resource Efficiency: Smart agriculture relies on innovative technologies, such as smart irrigation systems and sensor-based monitoring, to optimize the use of water, energy, and fertilizers. These technologies minimize resource waste, improve resource-use efficiency, and reduce environmental impacts.

-Reducing Production Costs and Improving Resource Utilization: Smart agricultural technologies reduce production costs through the precise use of agricultural inputs, minimizing waste, and optimizing the management of financial and human resources. This improves economic efficiency and increases farm profitability.

-Strengthening Food Security and Improving Nutrition: Smart agriculture plays a crucial role in increasing agricultural productivity and enhancing crop quality, ensuring the availability of sufficient, safe, and nutritious food. This contributes to improved food security and better nutritional outcomes, particularly in the face of
population growth and climate change.

3.1.2. Key Digital Technologies in Smart Agriculture Across the Arab World

Several advanced agricultural technologies have been adopted across Arab countries to improve agricultural productivity and resource efficiency. The most notable include: (Soudani, Ben Aichouba, & Sedkaoui, 2022, p. 468)

-Mechanized Tillage and Harvesting: The use of agricultural machinery, including tractors and harvesting equipment, has become a key driver of agricultural modernization in the Arab world. These technologies improve farming operations,

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increase productivity and crop yields, intensify agricultural activities, and reduce labor and production costs.

-Conservation (No-Till) Farming Systems: No-till farming has proven effective in preserving soil fertility and improving land-use efficiency. This technology was first introduced in Sudan in 2000 and has since been adopted by several Arab countries, including Syria, Tunisia, Lebanon, and Jordan.

-Modern Irrigation Technologies: Advanced irrigation systems have been successfully implemented in several Arab countries, particularly Iraq. These include sprinkler irrigation, which has been widely adopted by cereal producers, as well as surface and subsurface drip irrigation systems that improve water-use efficiency and are extensively used in vegetable production.

-Unmanned Aerial Vehicles (UAVs): Several Arab countries, including the United Arab Emirates, Saudi Arabia, Morocco, Tunisia, and Algeria, have developed or adopted UAV technology. While initially used for military purposes, drones are increasingly being deployed in agriculture. Their adoption accelerated during the COVID-19 pandemic, as they enabled remote crop monitoring, climate forecasting, and the early detection of pests and diseases, reducing the need for manual field operations.

3.2 Status of the Agricultural Sector in the Arab World

3.2.1 Agricultural Lands: Agricultural land is one of the key resources supporting agricultural activity and food security. Its area and patterns of use vary across Arab countries depending on climatic and natural conditions, as well as the availability of water resources. During **2019–2022**, it is important to distinguish between permanent and seasonal agricultural land, as well as rainfed and irrigated agriculture, in addition to forest and pasture areas. This provides a clearer picture of changes in agricultural resources and their utilization.

Table 1. Types and Areas of Agricultural Land in Arab Countries, 2019–2022 **(Million Hectares)**

Indicator	2019	2020	2021	2022
First: Total Agricultural Area	76.5	79.4	78	79
1. Permanent Agricultural Land	13.7	13.6	14.2	14.7
A. Rainfed Agriculture	9.7	10.1	10	10.4
B. Irrigated Agriculture	3.9	3.4	4.2	4.3
2. Seasonal Agricultural Land	62.8	65.8	63.7	64.2
A. Rainfed Agriculture	38.5	40.5	38	38.3
B. Irrigated Agriculture	11.9	13.4	12	12.1

Pasture Land (Fallow Land)	12.5	11.8	13.7	13.7
Second: Forest Area	38.7	39.4	38.8	38.3
Third: Pasture Area	412.4	416.3	399	404.5

Source: (AMF, 2023, p. 31)

The table illustrates the evolution of agricultural, forest, and pasture areas in the Arab region during the period 2019–2022, measured in million hectares. The main trends can be summarized as follows:

-Total Agricultural Area: Total agricultural area increased from 76.5 million hectares in 2019 to 79.4 million hectares in 2020, before declining to 78 million hectares in 2021 and rising again to 79 million hectares in 2022. This indicates limited annual fluctuations, with an overall trend toward relative stability.

-Permanent Agricultural Land: Permanent agricultural land increased from 13.7 million hectares in 2019 to 14.7 million hectares in 2022, representing an increase of 1 million hectares. This reflects a relative expansion in the area devoted to permanent agricultural activities.

-Rainfed and Irrigated Agriculture: Within permanent agricultural land, rainfed agriculture increased from 9.7 million hectares in 2019 to 10.4 million hectares in 2022, despite some fluctuations during the period. Irrigated agriculture also increased from 3.9 to 4.3 million hectares, indicating a relative expansion in areas dependent on irrigation.

-Seasonal Agricultural Land: Seasonal agricultural land increased from 62.8 million hectares in 2019 to 65.8 million hectares in 2020, then declined to 63.7 million hectares in 2021 before increasing to 64.2 million hectares in 2022. This category remained the largest component of the total agricultural area.

-Seasonal Rainfed Agriculture: Seasonal rainfed agriculture increased from 38.5 million hectares in 2019 to 40.5 million hectares in 2020, then declined to 38 million hectares in 2021, before reaching 38.3 million hectares in 2022.

-Seasonal Irrigated Agriculture: Seasonal irrigated agriculture increased from 11.9 million hectares in 2019 to 13.4 million hectares in 2020, then decreased to 12 million hectares in 2021, before recording a slight increase to 12.1 million hectares in 2022.

-Fallow Land: Fallow land increased from 12.5 million hectares in 2019 to 13.7 million hectares in 2021 and remained at the same level in 2022. This indicates the existence of a considerable proportion of agricultural land that is not being fully utilized.

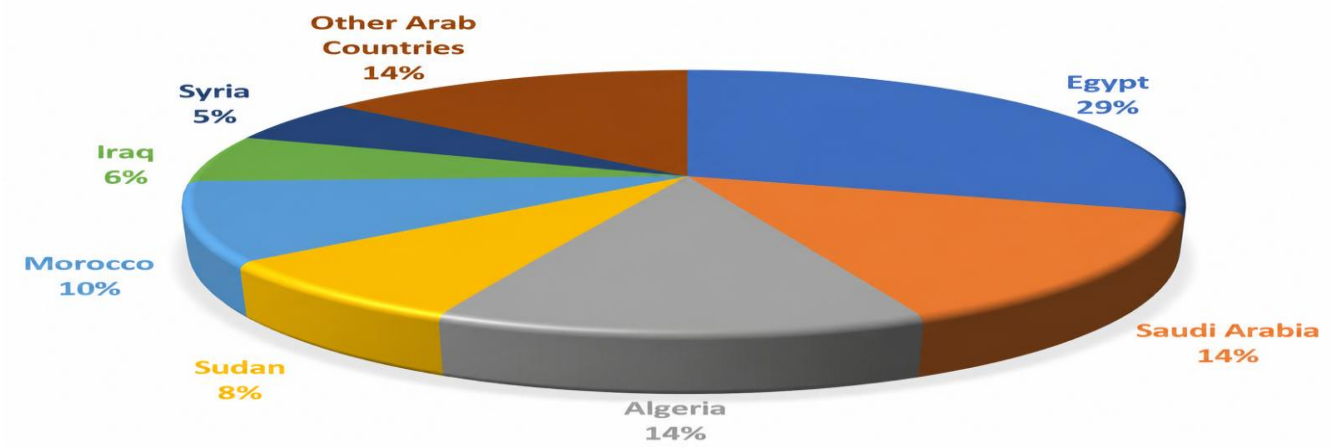
-Forest Area: Forest area declined slightly from 38.7 million hectares in 2019 to 38.3 million hectares in 2022, after increasing to 39.4 million hectares in 2020. This fluctuation may reflect the continued pressures affecting forest resources.

-Pasture Area: Pasture area amounted to 412.4 million hectares in 2019, increased to 416.3 million hectares in 2020, then declined to 399 million hectares in 2021 before recovering to 404.5 million hectares in 2022. Pastureland remained the largest land category in terms of area compared with agricultural and forest areas.

Overall, the data reveal relative stability in the total agricultural area, despite some annual fluctuations, alongside a moderate increase in permanent and irrigated agricultural land. In contrast, pastureland continues to account for the largest share of the total area, although it experienced noticeable fluctuations during the period. The persistence of substantial areas of fallow land also indicates the existence of agricultural potential that has not been fully exploited. This highlights the importance of adopting smart agriculture technologies to rationalize the use of water and other resources, improve land productivity, and strengthen food security in Arab countries.

3.2.2. Agricultural Crop Production:Food availability is a key dimension of food security, reflecting countries' ability to provide sufficient food supplies through domestic production or imports. The Arab region has a comparative advantage in producing fish, vegetables, fruits, and livestock products, while it remains highly dependent on imports of cereals, sugar, and vegetable oils. The adoption of smart agricultural practices has contributed to the growth of major crop production in Arab countries between 2019 and 2023.

Fig. 9. Average Agricultural Production Value in the Arab Countries, 2019–2023



Source: (AMF, 2023, p. 29)

The figure shows the distribution of the indicator among selected Arab countries. Egypt accounts for the largest share (29%), followed by Saudi Arabia and Algeria (14% each). Morocco represents 10%, while Sudan accounts for 8%. Iraq and Syria have smaller shares of 6% and 5%, respectively, whereas the remaining Arab countries collectively represent 14%. Overall, the distribution is relatively concentrated, with Egypt alone accounting for nearly one-third of the total, while the other countries contribute varying shares. This highlights the significant weight of Egypt in the regional distribution of the indicator.

3.3. Successful Arab Experiences in Smart Agriculture

3.3.1. The Tunisian Experience: Tunisia is widely recognized as one of the leading Arab countries in the adoption of smart agriculture technologies. The country has integrated sensors into irrigation networks and agricultural soils to monitor key farming indicators in real time. These sensors are connected to a wireless control unit linked to a digital platform that enables farmers to monitor soil salinity and manage the application of mineral nutrients to improve crop productivity. The system also facilitates centralized irrigation and fertilization management while providing early detection of leaks in drip irrigation networks, thereby improving water-use efficiency and enhancing agricultural productivity (Sayari & Jebli, 2023, p. 46)

3.3.2. The Egyptian Experience: Egypt has made significant progress in adopting smart agriculture technologies by integrating the Internet of Things (IoT) and information and communication technologies (ICT) into its agricultural sector, particularly in potato cultivation. In collaboration with the Electronics Research Institute, smart sensors have been developed to monitor soil and crop conditions, while mobile applications are used to support farm management and agricultural operations. These initiatives have reduced dependence on imported sensors and strengthened the use of locally developed technologies. Nevertheless, the wider adoption of smart agriculture continues to face challenges, including reliance on imported equipment and software, as well as a shortage of specialized technical expertise. Egypt also employs remote sensing technologies to analyze soil characteristics and water resources, assess crop conditions, forecast yields, optimize crop selection, monitor farms, detect pests and diseases at an early stage, and track drought impacts, thereby improving agricultural productivity and sustainability. (Chaa & Hadri, 2023, p. 230)

3.3.3. The Kuwaiti Experience: Kuwait is characterized by limited water resources, an arid desert climate, and predominantly sandy soils with low fertility, containing approximately 95% sand and low levels of organic matter and essential nutrients. To address these challenges, Kuwait has invested in scientific research and climate-smart agriculture to improve agricultural systems, support sustainable development, and strengthen food security under changing climatic conditions. Key initiatives include: (Mebrek & Sissani, 2024, pp. 44-45)

-Controlled Environment Plant Factory: In collaboration with the University of Guelph (Canada), the Desert Agriculture and Ecosystems Program developed and tested a smart agricultural system designed to enhance food security while reducing the intensive use of natural resources.

-Capillary Irrigation System: This environmentally friendly, soilless closed-production system uses capillary irrigation to cultivate ornamental plants and selected high-value vegetable crops while minimizing water consumption.

-Agricultural Box Technology: This soilless cultivation technique is particularly suitable for arid regions. It enables the repeated reuse of growing media and cultivation containers for multiple crop cycles, reducing labor requirements, saving time, and improving production efficiency.

3.3.4 The Lebanese Experience: Lebanon has emerged as a promising example of smart agriculture through the development of innovative start-ups focused on improving the efficient use of natural resources. One notable initiative is a vertical farming company that has reduced water consumption by up to 90% through an integrated water recycling system. In addition, Robinson Agri, a company specializing in greenhouse technologies, has developed advanced smart irrigation solutions based on the precise management of water according to crop requirements. These innovations contribute to water conservation, enhance agricultural productivity, and promote the sustainability of farming systems under conditions of limited water resources. (Mokaddam & Fares, 2023, p. 68)

3.3.5. The Algerian Experience

3.3.5.1. Requirements for Smart Agriculture to Enhance Food Security and Address Climate Change in Algeria

Algeria has adopted several strategic measures to expand the implementation of smart agriculture as part of its efforts to strengthen food security and improve the resilience of the agricultural sector to climate change. The main initiatives include: (Boukleikha, 2022, p. 438)

-According to the latest Global Food Security report issued by the United Nations, Algeria ranks first in Africa in terms of food security, with a score of 63.9%, placing it among the countries capable of supporting the United Nations' goal of achieving Zero Hunger by 2030.

-Promoting the adoption of advanced agricultural technologies, particularly through the integration of renewable energy into irrigation systems and the use of solar-powered pumping instead of diesel-powered engines, resulting in energy savings estimated at 15–40%.

-Providing government financial support for projects aimed at strengthening food security, particularly in the production of poultry and essential food commodities, while continuing policies that encourage agricultural exports.

-Agriculture contributes approximately 13% of Algeria's Gross Domestic Product (GDP), representing an estimated value of US$25 billion, highlighting its strategic role in the national economy and its importance for sustainable development.

3.3.5.2. Challenges of Smart Agriculture for Achieving Sustainable Food Security in Algeria: Despite the progress achieved, the adoption of smart agriculture in Algeria continues to face several challenges that must be addressed to ensure sustainable food security. The main challenges include: (Bouabdelli & Gharbi, 2023, p. 325)

-Supporting young innovators and entrepreneurs by providing the necessary incentives and facilities to encourage their participation in agricultural investment and the modernization of production systems, thereby contributing to national food security.
-Promoting climate-smart agriculture through the adoption of modern production systems and strengthening agricultural research and innovation to enhance national capacities and improve the sustainability and competitiveness of the agricultural sector.
-Repositioning agriculture as a strategic source of employment by creating job opportunities for young people and equipping the workforce with the digital skills required for modern farming, particularly as large-scale farms increasingly rely on smart technologies and mobile-based agricultural management systems

3.4. Requirements and Challenges of Smart Agriculture for Achieving Sustainable Food Security in the Arab World

3.4.1. Requirements for Investing in Smart Agriculture to Strengthen Food Security in the Arab World:Achieving sustainable food security through climate-smart agriculture in the Arab world requires the implementation of comprehensive policies and strategies that promote climate resilience and reduce greenhouse gas emissions. The main requirements include: (Beltehat, 2024, pp. 260-261)

-Identifying appropriate agricultural systems, practices, and technologies while establishing an enabling institutional framework that reflects the social, economic, environmental, and climatic conditions of each country.
-Developing supportive legislation and regulatory frameworks to facilitate the establishment of the infrastructure required for the effective implementation of smart agriculture technologies.
-Strengthening technical capacities by providing the methodologies, tools, and expertise necessary for conducting agricultural assessments, monitoring, and data analysis.
-Expanding beyond small-scale pilot projects to demonstrate the full potential of smart agriculture and encourage its large-scale adoption.
-Enhancing international cooperation with countries that have advanced experience in smart agriculture to promote technology transfer and support future applications, including the smart management of greenhouse farming.
-Fostering collaboration between governments and society, recognizing that addressing food security and climate change requires coordinated action, as the two challenges are closely interconnected.

3.4.2. Challenges Facing Smart Agriculture in the Arab World: The relatively slow adoption of smart agriculture in many Arab countries can be attributed to several

economic, technical, and institutional challenges, including: (Soudani, Ben Aichouba, & Sedkaoui, 2022, pp. 471-472)

-Limited telecommunications and internet infrastructure in some Arab countries, which restricts the deployment of digital agricultural technologies.

-Insufficient technical skills among farmers, as many lack the knowledge and training required to effectively use smart agricultural technologies.

-High implementation costs, which remain a major barrier to the widespread adoption of advanced agricultural technologies, particularly among small-scale farmers.

-Environmental constraints, including high soil salinity, water salinity, soil acidity, and limited irrigation water, which reduce agricultural productivity in many regions.

-Weak intra-Arab cooperation in agricultural technology and innovation compared with cooperation between Arab countries and international partners, limiting regional knowledge exchange and technology transfer.

-Diverse agroecological conditions, which require the development and adaptation of technologies tailored to local environments, resulting in additional investment and implementation costs.

-Unsustainable agricultural practices, which have contributed to soil degradation, declining soil fertility, reduced productivity, and increased land degradation and desertification in several Arab countries.

-Employment-related challenges, as many Arab countries continue to rely on agriculture as a source of employment, whereas global agriculture is increasingly shifting toward technology-driven and digitally managed farming systems.

4. RESULTS AND DISCUSSION :Based on the analysis presented in this study, the following conclusions can be drawn:

-The study confirms that smart agriculture is one of the most effective modern approaches for transforming the agricultural sector in the Arab world through the integration of advanced digital technologies.

-The adoption of smart agriculture enhances agricultural productivity, improves the efficient use of natural resources—particularly water—and contributes significantly to achieving sustainable food security.

-Despite its considerable potential, the implementation of smart agriculture in many Arab countries remains constrained by inadequate digital infrastructure, high technology costs, and a shortage of skilled professionals.

-Successful experiences in countries such as Tunisia, Egypt, and Kuwait demonstrate that smart agriculture can effectively improve agricultural productivity, optimize resource management, and strengthen food security.

5. CONCLUSION *:*This study has demonstrated that smart agriculture has become a key driver of agricultural transformation and a strategic approach to achieving sustainable food security. Rapid technological advancements, particularly in digital technologies, artificial intelligence, the Internet of Things (IoT), remote sensing, drones,

and precision farming, have significantly enhanced the efficiency and sustainability of agricultural production. By optimizing resource use, improving productivity, and strengthening resilience to climate change, smart agriculture offers effective solutions to the growing challenges of food security in the Arab world. Although several Arab countries have made notable progress in adopting smart agricultural practices, further efforts are required to overcome existing technical, financial, and institutional barriers to ensure their wider implementation.

6. Recommendations:Based on these findings, the study proposes the following recommendations:

- Increase public and private investment in smart agriculture technologies to enhance agricultural productivity and strengthen food security across the Arab world.
- Develop digital infrastructure and communication networks to facilitate the effective adoption of modern agricultural technologies.
- Support scientific research, innovation, and capacity building in smart agriculture through universities, agricultural research centers, and specialized training programs.
- Strengthen regional cooperation by promoting the exchange of knowledge, technologies, and successful experiences among Arab countries to foster sustainable agricultural development and enhance long-term food security.

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