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Carbon Smart Agriculture for Agricultural Sustainability - as a review

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Abstract: Carbon -smart agriculture is an ideal approach to dealing with climate change, which has become a tangible reality, as climate-smart agriculture plays an important role in reducing the effects of climate change on the agricultural sector by being a new agricultural method to direct the required changes to agricultural systems to achieve the greatest possible food security, while paying attention to agricultural natural resources and reducing carbon emissions to the lowest possible level. The world has moved towards developing practical agricultural methods by making them more dependent on modern technological techniques and increasing their ability to adapt to climate change and meet the growing demand for food to meet the needs of population growth, which is known as carbon-smart agriculture. The term smart agriculture has emerged as one of the results of the fourth technological revolution, as computational techniques, remote sensing devices, remote-operated machines and other modern tools and modern technological techniques have been adapted to increase the productivity and quality of agricultural crops and resist climate change through flexible smart agricultural practices that adapt to climate change. Mechanisms and criteria for transformation to implement the climate-smart agriculture approach. The scientific review aims to identify the carbon-smart agriculture approach and ways to achieve sustainable agricultural development through the application of carbon-smart agriculture methods, processes and practices.

Ker Words: Carbon Smart Agriculture, Climate Change, Agricultural Sustainability

1. Introduction

Carbon-smart agriculture is an ideal approach to dealing with climate change, which has become a tangible reality, as carbon-smart agriculture plays an important role in reducing the effects of climate change on the agricultural sector by being a new agricultural method to direct the required changes to agricultural systems to achieve the greatest possible food security, while paying attention to agricultural natural resources and reducing carbon emissions to the lowest possible level. The world has moved towards developing practical agricultural methods by making them more dependent on modern technological techniques and increasing their ability to adapt to climate change and meet the growing demand for food to meet the needs of population growth, which is known as carbon-smart agriculture. The term smart agriculture has emerged as one of the results of the fourth technological revolution, as computational techniques, remote sensing devices, remote-operated machines and other modern tools and modern technological techniques have been adapted to increase the productivity and quality of agricultural crops and resist climate change through flexible smart agricultural practices that adapt to climate change. Mechanisms and criteria for transformation to implement the carbon-smart agriculture approach.

Carbon-smart agriculture is an approach developed by the Global Alliance for Carbon-Smart Agriculture at the Food and Agriculture Organization(FAO).

The purpose of this approach is:

1. Increase the productivity and quality of agricultural production and thus increase farmers' income "economic dimension"

2. Reduce emissions resulting from various agricultural activities to the lowest possible level "environmental dimension"

3. Implement good agricultural practices that are smart and climate-resilient, which are considered adaptation transactions or mitigation of the negative effects of climate change on the agricultural sector "social dimension"

The carbon-smart agriculture approach acts to reduce the use of agricultural chemicals " synthetic fertilizers and pesticides" and other pollutants and work to preserve the agricultural environment to make it a sustainable agricultural environment. The approach also works to manage agricultural operations in a comprehensive manner and act to continuously improve them. Thus, gaining the confidence of farmers, suppliers, importers and consumers of fresh food.

Carbon-smart agriculture is one of the main pillars for facing future challenges in the agricultural sector, whether for large investors or small farmers. It is expected that it will become necessary to apply this approach to ensure the sustainability of productivity and the limited resources facing countries, especially in light of rapid climate change.

Carbon-smart agriculture seeks to improve efficiency and reduce waste in the use of resources, which helps adapt to these challenges with the increasing interest in food security and reducing the effects of climate change, the application of climate-smart agriculture will be necessary to ensure the provision of food in a sustainable and safe manner for future generations. Moreover, global markets are increasingly moving towards sustainable agricultural practices, where it will be necessary to reduce the use of chemical fertilizers and pesticides, and reduce carbon emissions. In this context, it will be important to apply the carbon-smart agriculture approach, which relies on modern technology in managing resources and achieving the highest levels of production and quality. Also, with the move towards “organic agriculture” and global trade, tracking systems such as “barcodes” will be activated in international markets, which enhances the importance of implementing carbon-smart agriculture and reducing the carbon footprint. Through this, farmers will be able to meet export requirements, while maintaining crop quality, thus improving competitiveness in global markets. Future expectations indicate that climate-smart agriculture will play a pivotal role in enhancing food security and increasing productivity under changing conditions, making it a promising option for the future in various parts of the world.

Carbon smart agriculture, including the use of traditional and modern technologies, is critical to achieving a sustainable agricultural system through three main pillars: increasing agricultural productivity through the optimal utilization of natural resources and reducing greenhouse gas emissions. The phenomenon of global warming and adaptation to future climate change and mitigation. The application of carbon smart agriculture will bring many benefits to the agricultural system by promoting improved horticultural and field productivity and access to safe and high-nutritious agricultural products and will reduce agricultural inputs such as pesticides and chemical fertilizers, which are a burden on the environment through pollution and emissions reduction, harmful pollutants and gases. The application of carbon- smart agriculture depends on certain transactions that will eliminate or minimize greenhouse gas emissions. The carbon footprint means recognizing the amount of emissions of any product during the production process of this product at different stages. Agricultural products, especially horticultural crops of vegetables and fruits.

The agriculture industry nowadays is experiencing rapid growth and adopting advanced technologies in order to bolster the overall yield of the all crops. Accessibility of a huge number of equipment's and state of the art technologies like intelligent monitoring system, drones, and robots, among others has totally revolutionized this important sector. Advanced technologies such as remote sensing technology accompanied by the 3D laser scanning are helpful and can provide crop metrics across thousands of acres of farming land. It can bring revolutionary changes from the perspective of time and efforts are monitored by the farmers. With the help of emerging solutions, farmers and farm enterprises can make better decisions during the farming as well as can assess a variety of things like weather conditions, temperature, water usage, or soil conditions in real-time.

The Expert System is one of the applications of artificial intelligence in many fields such as medicine and agriculture. It is a computer program that simulates the specialized expert "expert group" which is consulted to solve a specific problem. Experiences needed by the user "farmer or agricultural producer" in a specialty to solve a specific problem, the expert system asks the user the same questions asked by the expert and from the user's answers the system reaches the appropriate solution. The practical application of the expert system in the agricultural sector has proved that it can contribute to solving many agricultural problems in record time which positively reflects on the increase of production.

Smart fertilizer technology in agriculture sector

Indeed, the best management practices for fertilization are those that support the achievement of the main goals of sustainability of agriculture: productivity, profitability and environmental health. One of the main pillars of this vision is smart fertilization to improvement in crop production **Manjunatha *et al.*, 2016**, and **Morales-Díaz *et al.*, 2017**. Nanotechnology can play an important part and role in promoting agricultural sustainability, after providing the viability of so-called "smart fertilizers". In other words, nanostructures act as a carrier of the nutrients and allow for controlled release.

Smart pesticides technology in agriculture sector

Chemical pesticides are mightily used to improve agriculture production and quality. However, chemical pesticides are unsuitable due to increase hazards for human health and environment. Nanotechnology has great potential to protect plants from diseases, virus, pests, weeds, diagnose of plant diseases, improve food yield and quality **Frewer *et al.*, 2011** and **Sonkaria *et al.*, 2012**. Nanoencapsulated pesticides can supply controlled release kinetics and improving solubility, permeability, stability, and efficiency **Kumar *et al.*, 2019** and **Kumara *et al.*, 2019**. The utilization of nanotechnology to originate novel pesticide formulations has shown great possibility for providing environmentally safer alternatives.

General indicators for measuring and verifying the application of climate-smart agriculture curriculum standards:

1- Estimating the extent of reducing carbon emissions from the agricultural sector compared to the baseline.

2- Estimating the extent of the per capita “farm” or farm – compared to the baseline “comparing carbon emissions before and after applying climate-smart and flexible agricultural practices and transactions".

3- Measuring the extent of growth and progress in the agricultural sector "farms that apply the criteria of climate-smart agriculture" compared to the baseline.

4- The percentage of increase in productivity and quality of farms applying the criteria of the carbon-smart agriculture approach compared to the baseline.

5- Evaluation of the performance and development of the monitoring and early warning system for the effects of climate change on the agricultural sector.

6- Evaluation of the crisis management plan related to climate change and its effects on the agricultural sector system.

7- Evaluation of progress in performance indicators related to climate change.

8- Evaluating the volume of investments directed to the agricultural sector to combat climate change.

9- Evaluation of the volume of policies and projects supporting measures to mitigate and adapt to climate change and its impact on the agricultural sector.

10- Evaluation of the existence of a database of research efforts in the field of climate change.

Proposed standards for the climate-smart agriculture curriculum

The criteria for the climate-smart agriculture approach must take into account the pillars of the approach, which are as follows:

1. Increasing the productivity and quality of the agricultural sector and increasing the incomes of farmers and agricultural producers.
2. Act to reduce carbon emissions to the lowest possible level.
3. Act on conducting smart, flexible agricultural transactions and practices that contribute to acclimatization and mitigate the effects of climate change on the agricultural sector.

Adaptation practices

1. Intercropping agricultural crops.
2. Irrigation systems management.
3. Modern farming systems "soilless farming - hydroponic."
4. Conducting the grafting process in some vegetable crops to adapt to unfavorable conditions.
5. Using solar energy to operate irrigation machines.
6. Establishing agricultural meteorological stations and taking advantage of weather information to provide smart agricultural guidance on programs on farmers' mobile phones.
7. Production of industrial organic fertilizers "compost" by recycling the residues "agricultural waste."
8. Biogas production.
9. Fodder production "from the remains of agricultural crops"
10. Cultivation and cultivation of barley as "non-traditional fodder."
11. Cultivation on bales of "the remains of some agricultural crops."
12. Cultivation and production of mushrooms.
13. Establishing environmental services that achieve the concept of innovation and technology, such as irrigation using solar energy, growing algae, growing Paulina trees.... etc.
14. Establishing an eco-tourism program.
15. Recycling palm waste to produce high-value environmental products.

16. Programs to encourage industries that depend on agricultural crops
17. Building the capacities of the agricultural community to face the effects of climate change.
18. Establishing an information center for agricultural climate change.
19. Establishing greenhouses to produce agricultural seedlings adapted to climate changes.
20. Programs to support fishing as an economic activity complementary to agricultural activity.
21. Courses of maintenance, follow-up and environmental monitoring of the negative effects resulting from reducing pollution affecting crops and livestock.
22. Establishing a green belt around agricultural and residential areas as well.
23. Establishing a partnership system to monitor emissions and electronic control of factories in order to preserve the surrounding agricultural environment
24. Establishing a special unit for agricultural climate research, in partnership with development partners, to control marketing crops

Methods for improving agriculture

In order for the agricultural sector to play its full role in economic and social development, some methods and approaches must be applied that help increase and improve agricultural production, including the following:

• Good planning for the growth of the agricultural sector and investing it properly

• Developing a clear and accurate agricultural policy

• Monitoring the annual production of fields and evaluating their performance

• Planting seeds for good and improved varieties of horticultural and field crops

• Using appropriate means for water drainage

• Getting rid of harmful weeds early

• Rationalizing the use of agricultural fertilizers, and choosing the appropriate ones

• Maintaining and preserving natural resources

• Providing experts and trained workers to develop agricultural development projects

• Raising the level of agricultural production in line with the interests of the national economy

• Achieving harmony and integration between the various branches of agricultural activity

• Benefiting from the results of agricultural scientific research in the applied field

Smart Agricultural Automation:

Harvesting by agricultural automation and robotics is one of the key technologies in modernizing agriculture.

For the world's agricultural production countries, including the United States, Japan, the Netherlands, the United Kingdom, Belgium, etc., agricultural automation has become the hottest trend today.

Usually, design companies will provide their various solutions for harvesting vegetables and fruits

- The role of Internet of Things in smart agriculture.

Practical applications of Internet of Things in agriculture:

Soil and crop monitoring

Precision agriculture and input management

Livestock monitoring and management

Greenhouses and indoor agriculture automation

Weather and environment monitoring

Smart irrigation and water management

Supply chain tracking and marketing

Sensors and IoT devices

A vast ecosystem of connected sensors spread across fields measures and monitors key data points such as humidity, temperature, rainfall, soil nutrients, leaf health, agricultural equipment operations, and many other agricultural factors.

- Artificial Intelligence Technologies and Their Uses in Smart Agriculture

1- Monitoring Crop and Soil Health

2- Detecting Insects and Plant Diseases "Agricultural Pests"

3- Monitoring Livestock Health

4- Smart Pesticide Spraying

5- Automatic Weed Removal

6- Aerial Survey and Photography

7- Classifying and Sorting Agricultural Products

The need to apply the climate-smart agriculture approach:

Working to spread and localize climate-smart agriculture applications and technologies will inevitably result in maximizing agricultural production, through:

Improving the efficiency of using all agricultural inputs (fertilizers and pesticides)

Improving the efficiency of using agricultural machinery

Improving crop productivity

Ensuring an appropriate profit for agricultural projects and farmers

Preserving natural agricultural resources from water sources and agricultural soil

Help in making decisions quickly by relying on software and programs on mobile phones

Using short messages "SMS" in advisory and awareness activities to communicate with farmers.

When these technologies and practices are applied together, by different stakeholders "small farms":

Reduces water loss

Reduces land degradation

Increases soil water availability

Gives equitable distribution of water resources

Enhances agricultural production and productivity

Enhances food security

Creates resilience to climate change

Economic feasibility of implementing the climate-smart agriculture approach:

The application of carbon-smart agriculture will achieve many benefits for the agricultural system from improving agricultural horticultural productivity and obtaining safe, healthy and high-nutritional agricultural products and will reduce the use of various agricultural inputs "synthetic fertilizers and chemical pesticides" which are considered a factor of pollution of agricultural resources of land and water and reduce harmful emissions. Accordingly, the use of the climate-smart agriculture approach and

practices will achieve an agricultural renaissance and a significant agricultural economic addition. It is worth noting that the use of the carbon-smart agriculture approach will not entail any additional economic burdens, but on the contrary will achieve a high economic return in the short and long term.

• The first steps necessary to start implementing the climate-smart agriculture approach:

The first step to spread the climate-smart agriculture approach is to communicate the concept of climate-smart agriculture to producers and farmers through agricultural awareness, traditional and smart agricultural guidance, agricultural media, and other means of communication with producers and farmers.

The second step is to benefit from the experiences of countries that preceded us in joining the Global Alliance for Carbon-Smart Agriculture and work to benefit from them and from the success stories of carbon-smart agriculture in different countries.

The third step is to continue attending and participating in global conferences and forums related to climate-smart agriculture, especially the annual forum of the Global Alliance for Climate-Smart Agriculture.

The fourth step is to evaluate the performance and manage the application of climate-smart agriculture in the field.

Definition of Carbon Smart Agriculture (CSA)

Carbon Smart Agriculture refers to a set of agricultural practices and technologies designed to reduce greenhouse gas emissions, enhance carbon sequestration in soils and biomass, and improve the resilience and productivity of farming systems under climate change. It integrates climate-smart crop management, precision agriculture, soil health improvement, renewable energy solutions, and circular bio-economy principles to create low-carbon, resource-efficient agricultural systems.

Detailed Explanation of Carbon Smart Agriculture

Carbon Smart Agriculture (CSA) is a modern framework that aligns agricultural development with global climate-change mitigation targets. The approach recognizes that agriculture is both a contributor to greenhouse gas emissions and a major opportunity for carbon sequestration. CSA aims to optimize farming practices to:

Reduce emissions from soil management, fertilizers, livestock, irrigation, and residue burning.

Increase carbon storage through practices such as conservation tillage, agroforestry, cover cropping, organic amendments, and biochar application.

Enhance resilience by improving soil structure, water-use efficiency, crop tolerance, and climate risk management.

Sustain productivity through data-driven decision support, smart irrigation, and climate-informed crop calendars.

The strategy leverages digital agriculture tools—AI, IoT sensors, drones, satellite data, and automated analytics—to monitor carbon flows, estimate emissions, and guide farmers toward optimal decisions. CSA also integrates carbon markets, allowing farmers to earn carbon credits through certified emission reductions. It promotes circularity by transforming agricultural waste into value-added products such as compost, biochar, and biogas, thereby closing nutrient loops and reducing dependence on synthetic fertilizers. Overall, Carbon Smart Agriculture contributes not only to climate mitigation but also to food security, economic efficiency, and environmental restoration.

Conceptual Foundations of Carbon Smart Agriculture

CSA integrates three interconnected objectives:

Mitigation – reducing emissions and enhancing carbon sequestration.

Adaptation – increasing resilience to climate stresses.

Productivity – sustaining or increasing agricultural outputs sustainably.

This tri-pillar approach ensures that climate action does not compromise food security.

Sources of Agricultural Emissions

Agriculture contributes significantly to global greenhouse gases:

CO_2 from land-use change and machinery.

CH_4 from rice paddies and enteric fermentation.

N_2O from fertilizers and soil processes.
Understanding these sources is essential for designing mitigation strategies.

Carbon Sequestration Strategies

Key approaches include:

Conservation tillage and no-till systems

Cover crops and green manures

Agroforestry and shelterbelts

Organic amendments (compost, manure, biochar)

Restoration of degraded lands

Improved grazing and pasture management

Smart Technologies in CSA

Digital agriculture is central to CSA:

IoT sensors for soil moisture, nutrients, and carbon levels

AI models for yield prediction and emission estimation

Remote sensing for biomass mapping

Drones for crop monitoring and precision input delivery

Smart irrigation and automated fertigation

These technologies enable real-time, evidence-based decisions.

Soil Health and Carbon Cycling

Healthy soils with high organic matter store more carbon and retain more water. Biological activity, aggregate stability, and nutrient cycling are all improved under CSA practices.

Water and Irrigation Management

Climate-smart irrigation technologies include:

Drip and subsurface irrigation

Automated scheduling using sensors

Solar-powered pumping systems

Rainwater harvesting and deficit irrigation strategies

These approaches significantly reduce energy use and emissions.

Barriers and Challenges

Challenges include:

High cost of technology

Limited technical capacity

Uncertain carbon market regulations

Need for training and extension services

Future Directions

Integration of robotics and automation

AI-driven carbon modelling

Climate-resilient crop varieties

Landscape-level carbon planning

National low-carbon farming policies

Smart Agriculture

Smart agriculture is the use of advanced technologies to improve agricultural production sustainably and efficiently, while minimizing environmental impacts and optimizing resource use.

It relies on integrating modern technologies such as artificial intelligence (AI), the Internet of Things (IoT), big data, and drones to monitor crops and allocate resources more efficiently.

Technologies Used in Smart Agriculture

1. Artificial Intelligence (AI)

• AI is used to continuously analyze data collected from agricultural fields. By analyzing this data, crops' water and nutrient needs can be determined, helping farmers make informed decisions about irrigation and fertilization.

• For example, AI can be used to predict weather and environmental changes, enabling farmers to take proactive measures to protect their crops.

2. Internet of Things (IoT)

The Internet of Things allows multiple devices to connect over the internet to collect and analyze data in real time. In smart agriculture, sensors are used to measure soil and air humidity, temperature, and light levels, enabling farmers to precisely control the environment surrounding their crops. • These devices provide consistently accurate data, enabling immediate decisions to improve crop growth.

3. Drones:

Drones are used to monitor farmland from the air. They can capture detailed images using multispectral cameras, providing precise data on crop health. This helps farmers identify areas requiring special attention (such as irrigation or pest control).

4. Big Data

In smart agriculture, massive amounts of data are collected from various sources, such as sensors and drones, and analyzed using big data technologies. This advanced analysis allows for accurate predictions of outcomes, such as next season's crops, and the optimal approach to addressing agricultural challenges.

Benefits

Increased Productivity: By improving the management of agricultural resources like water and fertilizer, productivity can be significantly enhanced. Some studies suggest that smart agriculture can increase production by up to 30-40% for certain crops.

Water and Resource Conservation: Using artificial intelligence and sensor technologies helps reduce water waste and promote more efficient fertilizer use. In water-scarce regions, these technologies can make a significant difference in resource conservation. • Environmental Sustainability: Smart agriculture contributes to reducing negative environmental impacts by minimizing the use of pesticides and chemical fertilizers, thus reducing environmental pollution and preserving biodiversity.

Challenges

• High Cost: Adopting modern technologies such as sensors and drones represents a high initial investment. Despite the long-term benefits, the cost can be a barrier for small farmers.

• Need for Advanced Skills: Smart agriculture requires advanced skills in using technology and analyzing data, which can be a challenge in some areas lacking sufficient expertise or training.

• Unequal Access to Technology: Some farmers in remote or developing areas may face difficulties accessing these modern technologies.

Expected Future:

Smart agriculture is expected to continue growing and evolving as technology advances. Farmers will benefit greatly, especially in light of global challenges such as climate change. Technology will provide innovative solutions for producing food more sustainably and efficiently.

Carbon-Smart Agriculture

Carbon-smart agriculture is an agricultural approach that aims to improve resource use efficiency, reduce negative environmental impacts, and enhance resilience to climate change. Its main features include:

Core Principles

1. Environmental Sustainability: Conserving natural resources and biodiversity.

2. Economic Efficiency: Improving productivity and reducing costs.

3. Social Equity: Enhancing food security and community participation.

4. Technological Innovation: Using modern technology to improve agriculture.

Key Strategies

1. Crop Selection: Selecting crops that are tolerant to climate change.

2. Water Efficiency: Reducing water use and improving irrigation efficiency.

3. Fertilization: Using organic fertilizers and reducing chemical fertilizers.

4. Transplanting: Planting crops at different times to reduce climate impacts.

5. Bioculture: Using living organisms to improve soil health.

6. Hydroponics: Using modern irrigation systems.

7. Tree Planting: Planting trees to improve soil quality and reduce erosion.

Technologies Used

1. Precision Agriculture: Using technology to improve the accuracy of farming.

2. Smart Irrigation Systems: Using sensors to improve irrigation efficiency.

3. Environmental Analytics: Using data to improve agricultural decisions.

4. Mechanized Agriculture: Using modern agricultural machinery to improve efficiency.

5. Agricultural Information Systems: Using software to improve farm management.

Benefits

1. Improved Productivity: Increasing agricultural production.

2. Reduced Costs: Lowering production costs.

3. Improved Soil Quality: Maintaining soil health.

4. Reduced Environmental Impacts: Reducing pollution and carbon emissions.

5. Enhanced Food Security: Improving food accessibility.

Carbon-Smart Agriculture and its Applications

The problem of climate change has taken on a profound dimension due to its negative repercussions affecting various aspects of life, particularly in the agricultural sector. This has led to consequences for the international and local food situation, pushing some countries to the brink of famine and the inevitable death of their populations due to food shortages and reduced crop and livestock production. Consequently, various countries and international organizations working in the fields of environment and agriculture have sought solutions and policies to mitigate these negative impacts. Among the adopted solutions is climate-smart agriculture, which has been praised by numerous international experiences. It is considered a highly suitable approach and tool for coexisting with climate change, which has become an undeniable reality. Furthermore, it is crucial in reducing agriculture's impact on the climate by lowering greenhouse gas emissions**. (Arab League Educational, Cultural and Scientific Organization, 2021).**

The Concept of Smart Agriculture

Smart agriculture represents a new concept that refers to the use of Fourth Industrial Revolution technologies and modern information and communication technologies in farm management in order to improve the quality and quantity of production, increase the efficiency of agricultural resource management, and rationalize their use. Smart agriculture has become the third green revolution after the plant breeding and genetics revolution **(Bouabdelli & Gharbi, 2023).** Therefore, we will attempt to address a set of definitions that provide an explanation clarifying what is meant by this type of agriculture:

The FAO defines it as "climate-smart agriculture as an approach to preparing the necessary measures to transform agricultural systems to support food security in the face of climate change, striving to achieve three main objectives: increasing productivity sustainably, adapting to and building resilience to climate change, and reducing greenhouse gas emissions produced by agricultural practices**." Al-Ani, 2023**

Also known as "Smart Farming 4.0" or "Digital Farming," it is the application of information and data technologies to improve complex farming systems. It encompasses individual machines and all processes and activities of the agricultural investor**. (Bouthelja, 2021)**

Furthermore, it is defined as "an agricultural system that relies on the application of advanced agricultural technologies to produce food in healthy ways, while preserving natural resources and rationalizing their use, i.e., ensuring the sustainability of these resources, increasing water use efficiency, reducing production input costs, and maximizing their benefit through the automation of agricultural processes such as irrigation, fertilization, pest control, soil and crop monitoring, obtaining, analyzing, and managing accurate data, and investing this data to precisely guide agriculture towards greater production at a lower cost. This enables appropriate decisions in the agricultural production process and the production of high-quality crops. Among the most important smart applications and technologies are remote control systems, autonomous machines, the Internet of Things (IoT), remote sensing, information and communication technology, and drones." The process, smartphone applications, robots and robotics, and vertical farming (**Al-Balawneh and Abu Sini, 2021).** Smart agriculture, according to the presented set of definitions, is one of the modern solutions to eliminate hunger and poverty, through which countries aim to increase production and productivity, improve agricultural crops, and help rural communities and farmers. It is based on cultivating crops that are better adapted to the effects of climate change and water scarcity, and in turn, it helps to address many of the problems facing countries.

The Importance of Smart Agriculture

Smart agriculture is of great importance today, which can be summarized as follows: **(Bouchnaf, 2023, p. 112)**

1- Ensuring food security and promoting sustainable agriculture by raising awareness about the use of information and communication technology (ICT) applications in agriculture, given their importance in achieving sustainable development.

2- Conserving natural resources and increasing the efficiency and sustainability of their use.

3- Improving agricultural practices by reducing costs and optimizing the use of agricultural resources.

4- Enhancing livelihoods and food security, especially for farmers and owners of small and micro enterprises in developing countries.

5- Supporting countries and clarifying the path for developing policies and technical and financial mechanisms in all circumstances.

6- Making agriculture more resilient, especially in light of climate change and fluctuations.

7- Providing food and sustainable food security for many countries and millions of people, as it reduces emissions and pollution, thus preserving the environment and resources for future generations—in other words, preserving the wealth of future generations. 8- It represents a more suitable and excellent solution for countries that rely on agriculture as a primary source of livelihood, as it reduces the impact of climate change on their agricultural resources and preserves their food security.

In addition,

1- It offers several smart solutions for agriculture and climate, which in turn achieve food security at the lowest cost, as it relies on a policy of recycling agricultural waste.

2- It also plays a role in maintaining land productivity by controlling the effects of climate change, and it helps in finding solutions that reduce problems related to agricultural irrigation.

3- It achieves the sustainability of the agricultural ecosystem by maximizing the use of natural resources and improving crop productivity and quality.

Objectives, Principles, and Components of Smart Agriculture

Smart agriculture has several objectives, or what is known in some references as principles, which are: **(Bouabdelli & Gharbi, 2023)**

1- Providing food security to avoid catastrophic climate changes, as well as achieving sustainable development.

2. Creating green jobs.

3. Reducing hunger and poverty.

4. Converting animal waste into biogas as an alternative and renewable energy source.

5. Establishing climate-resilient fisheries and aquaculture through storm-resistant fish cages and ponds, and adaptive fishery management.

6. Improving soil management and fertility.

7. Implementing sustainable natural resource management. Furthermore, according to **(Benchaa and Hadri ,2023),** any type of agriculture aimed at achieving food security is based on a set of principles. The same applies to smart agriculture in achieving food security and ensuring its sustainability. Its principles (or objectives) are:

1- Environmental Preservation and Protection: This is achieved through better management of natural resources, sustainable resource use, improved land and water sustainability, technologies that reduce chemical use, improved land mapping, and enhanced water management.

2- Improved Productivity: This applies to farm productivity in terms of yield, as well as increased asset management efficiency.

3- Fostering Innovation in Agriculture: Smart agriculture technologies allow for the adoption of innovative production methods in both animal and plant production, and at all stages of production, from the farm to the market.

4- Attracting New Investments: Given the natural diversity and arid climate in most Arab countries, this will encourage investors to adopt new agricultural technologies in challenging and harsh environments.

5- Creating Green Jobs: This allows for adaptation to climate change. Climate change and greenhouse gas emissions reduction.

6. Reduce hunger and poverty by increasing production and improving crop quality.

7. Convert animal waste into biogas: an alternative and renewable energy source.

8. Develop climate-resilient fisheries and aquaculture: through storm-resistant fish cages and ponds, and adaptive fishery management.

9. Increase revenue: Transparency in the value chain will raise confidence in food safety and traceability, leading to increased market value.

10. Create jobs: New jobs will be created as entrepreneurs and new players join the relatively new smart agriculture sector.

These principles only emerge when the three fundamental pillars of smart agriculture are present: **(Balhatat, 2024)**

1- Increased agricultural productivity: by enhancing crop and livestock management and promoting sustainable land and water management practices, which increases incomes, promotes sustainability, and protects the environment while achieving food security. Enhancing Resilience: This involves reducing farmers' exposure to various risks and improving their capacity to address the challenges they face through crop diversification and water and soil conservation. The goal of resilience is to make agricultural systems more adaptable to climate change and less vulnerable to its impacts (also intended to enhance human capacity to adapt to climate change).

2- Reducing Emissions: This focuses on support methods that reduce emissions from agriculture, such as integrated pest management, conservation agriculture, and the use of renewable energy in agriculture. The aim is to increase efforts to mitigate climate change while reducing agriculture's contribution to greenhouse gas emissions.

The Food and Agriculture Organization (FAO), in its report "Climate-Smart Agriculture," identified a set of key messages for implementing climate-smart agriculture, as follows: **(Bouthelja. 2020)**

1- Agricultural and food systems must undergo significant transformations to meet the challenges of food security and climate change. When developing agricultural policies, a climate-smart agriculture approach can act as a catalyst for achieving this.

2- Carbon-smart agriculture is not a new set of practices or systems. Sustainable production is an approach that aims to provide means for integrating specific adaptation and mitigation characteristics into sustainable agricultural development policies, programs, and investments.

3. Solutions are context-specific (in terms of both place and time). Therefore, analysis and consultation are necessary to determine the appropriate action for each context to sustainably improve food security.

3. Improved policy coordination is essential within the agricultural sector (crops, livestock, forestry, and fisheries) and other sectors (such as energy, water, and industry) to leverage potential collaborations, minimize trade-offs, and utilize natural resources and environmental services.

Aspects and Applications of Smart Agriculture (Its Areas): While numerous references exist on the aspects of smart agriculture, or its application areas, we have relied on **(Siyari & Jabli, 2023)** as it provides a comprehensive overview of all aspects. Through this approach, modern technologies play a crucial role in meeting the growing food needs of the population and achieving food security, which in turn makes agriculture more productive, profitable, less harmful to the environment, and less resource-intensive.

1- Modern Technology and Artificial Intelligence in Agriculture (Smart Agriculture): This type of artificial intelligence technology relies on algorithms and mathematical models to process the vast amounts of data collected daily from various sensors and Internet of Things (IoT) devices. It utilizes human-level cognitive abilities to make decisions and quickly gain an accurate understanding of

agricultural land conditions through data analysis, processing, and the generation of valuable predictions. These technologies can be classified into two categories:

First Classification: The use of modern agricultural technologies is a crucial step towards improving agricultural production efficiency. These technologies provide farmers and landowners with tools that help them understand their land and select appropriate farming equipment. This category is further divided into:

Modern agricultural technologies related to equipment: These include improvements to agricultural machinery such as self-driving tractors, automated grain unloading systems, electric drive systems, sprayers, irrigation equipment, and robots, which significantly reduce human physical effort.

Modern agricultural technologies related to information technology: These have revolutionized the agricultural sector and include GPS systems and remote sensing devices used to measure and monitor crop health. And the soil.

Modern agricultural techniques related to biotechnology: such as high-throughput screening for rapidly multiplying beneficial organisms, leading to the development of new biological species, including drought-resistant plants, and soil DNA testing.

The agricultural process, from its inception to harvest, is divided into:

Monitoring and surveillance systems, which include:

Satellite imagery: Recently, satellite imagery has been used for remote crop monitoring, saving time and money. This technology can also be integrated with soil, water, and crop sensors to provide alerts about potential hazards or resource shortages. One of the most important roles of satellites is weather forecasting, enabling farmers to determine optimal sowing times, postpone harvests, and other strategic decisions **(Al-Rawi, 2020)**.

Internet of Things (IoT): One of the greatest technological advancements in agriculture is the integration of IoT devices. These devices provide farmers with a comprehensive overview of everything from soil type and moisture levels to wind intensity, helping them identify numerous factors upon which to base their decisions. This has contributed to increased production by 56-118%. IoT sensors will be able to monitor nutrient levels in the field and provide farmers with precise insights into when and where to plant crops, maximizing yields and minimizing crop waste. In addition to air sensors that can be fitted to drones, which will give farmers real-time insights into the best weather conditions for planting and harvesting, making farming more efficient and productive, drones can provide live feedback on the health of individual plants or crops. This approach will save considerable time and allow for early intervention to prevent disease outbreaks.

• Blockchain digital security can be used to monitor the movement of food from farm to market to consumer, reducing spoilage and waste and identifying areas of greatest need **(Siyari & Jabali, 2023)**.

• Pest and insect control: According to the Food and Agriculture Organization of the United Nations (FAO), between 20% and 40% of the world's grain crop is currently lost due to pests and insects, which are among the most significant threats to crops globally before they are harvested and stored for human consumption. AI companies like FarmWise can help send alerts to farmers via their smartphones about insects, such as locusts, that may descend on a particular farm. These companies also utilize new satellite image analysis algorithms and compare them with previous image data, enabling farmers to take timely action to mitigate damage and eliminate costly pests **(Muath, 2022)**.

• Determining the type and location of pesticide spraying: Sensors detect and target weeds, pinpointing the appropriate spraying locations and types. This results in cleaner and safer food and reduces costs. Furthermore, software algorithms analyze foliage patterns to identify soil defects, pests, and plant diseases. The application can identify potential defects from images captured by the user's smartphone camera and then provide advice and possible solutions **(Al-Rawi, 2020).**

AI-powered equipment includes

• Agricultural robots: These are used to help farmers find more effective ways to protect their crops from weeds. Robots have been developed to assist farmers in harvesting and packing their crops, potentially

replacing up to 30 human workers with a single robot, thus addressing the labor shortage **(Siyari & Jabali, 2023)**.

• Self-driving tractors: Using a smart tractor facilitates plowing and sowing at even intervals, and can monitor growth levels and predict harvest times. They have proven highly beneficial, allowing for precise and calculated driving to avoid excessive soil compaction. This creates optimal conditions for crop growth and harvesting, and saves time by mapping suitable routes for harvesting operations. These tractors are programmed to independently detect the plowing location in the field, determine speed, and avoid obstacles such as irrigation equipment, people, and animals while performing tasks. With more high-quality training data for agriculture, the widespread use of these autonomous tractors will revolutionize farming **(Siyari & Jabali, 2023).**

Drones: The main benefits of using drones include crop health imaging, integrated GIS mapping, ease of use, time savings, and the potential to increase yields by collecting and processing data across a range of sensors. They also facilitate farm supervision tasks by their ability to cover hundreds of hectares in a single flight using infrared and multispectral images. Drones can gather a variety of information about soil and crop conditions, irrigation needs, crop growth, pathogen diagnosis, and fertilization of each plot of land according to its specific characteristics, thus contributing to future hunger eradication. They are used for crop monitoring and evaluation, agricultural land imaging and mapping, air composition measurement, and rapid and safe pesticide spraying. Data is transmitted instantly to software for analysis and better guidance for farmers, spraying crops up to five times faster than traditional machines. They also play a role in creating accurate 3D maps for preliminary soil analyses and data collection, as well as in managing irrigation processes and nitrogen levels **(Siyari and Jabali, 2023)**.

Vertical farming, or vertical agriculture, is the practice of growing produce stacked one on top of the other in an enclosed environment. It is often associated with urban agriculture due to its ability to thrive in limited space. Unique in this method, the plants do not require soil; most are hydroponically grown, with their roots regularly sprayed with water and nutrients. Humans cannot establish this type of farm without relying heavily on technology to monitor the plants and precisely control light, humidity, and other conditions that are difficult for humans to accurately determine. Vertical farming involves producing food on vertically inclined surfaces, rather than cultivating vegetables and other crops on a single level. Food is produced in vertically stacked layers, commonly integrated into structures such as skyscrapers, shipping containers, or repurposed warehouses. Artificial control of temperature, light, humidity, and gases makes indoor food and pharmaceutical production possible. Similar to greenhouses, where metal reflectors and artificial lighting enhance natural sunlight, the primary goal is to maximize crop production in confined spaces. Vertical farming is not only a means of securing local food supplies but also a solution to some environmental problems. Following the principles of zero waste, vertical farms tend to maximize resource utilization and reuse waste. Water used for irrigating crops on the upper floors slowly drips down to the lower floors to irrigate fruits and vegetables. Waste not used as animal feed on the lower floors ends up in a designated area with other organic waste, where it is converted into compressed bio-balls using solar-powered furnaces. These bio-balls are then used as fuel to generate energy. Furthermore, through a material recycling program, water vapor produced by the plants can be converted into purified water, which is sold in restaurants and markets located on the lower floors, for example. Increasing production from a small growing area is not the only advantage of vertical farming; it also plays a vital role in preparing for the future: increasing crop yields year-round; using less water for agriculture; being unaffected by unpredictable weather conditions; increasing organic crop production; and being safe and environmentally friendly **(Siyari & Jabali, 2023).**

Modern Agricultural Greenhouses: Due to recent significant technological advancements, greenhouses have become Modern systems with automated control mechanisms adapt the agricultural environment. High-tech LED lighting is used to protect against the effects of external environmental factors. Greenhouses, which are glass structures that protect crops from external elements such as rain, wind, temperature, and pests, are equipped with advanced technology, including motor control algorithms and sensors for irrigation, heating, and lighting. This allows for optimal climate control based on measured data, thus improving crop production. The greenhouse sector captured the largest share of the global digital agriculture market in 2020. People use greenhouses to cultivate all kinds of plant crops.

The world's largest greenhouse project, the Eden Project, boasts over 100,000 plants and cultivates more than 5,000 different varieties using digital technologies and the latest advancements in agricultural technology. The ability to cultivate diverse crops outside their natural environment in greenhouses has significantly contributed to the sector achieving the largest market share in the global digital agriculture market **(Siyari & Jabali, 2023)**.

Internet of Things (IoT) Applications in Agriculture

The Internet of Things (IoT) is one of the most prominent technologies used in smart agriculture. Its core principle is the ability to extract data from objects and transmit it via the internet to improve the agricultural process. Simply put, it's the process of connecting any device to another via the internet, from mobile phones to household appliances and machinery used in agricultural fields, allowing them to be operated, controlled, and send and receive data over the internet. These devices collect and process data repeatedly, enabling farmers to respond quickly to emerging issues and changing environmental conditions. One of its most important applications in agriculture is described below **(Siyari & Jabali, 2023).**

Precision Agriculture: This is a type of agriculture that relies on technology, satellites, the Global Positioning System (GPS), and Geographic Information Systems (GIS) to understand the various variables related to the agricultural process, such as determining appropriate irrigation and fertilizer quantities, and predicting harvest periods and quantities. It allows for decisions to be made per square meter or per plant, rather than per field, by accurately measuring variations within the field **(Siyari & Jabali, 2023)**.

Nanotechnology and Precision Agriculture: This involves using fertilizers, pesticides, and herbicides within nanocapsules that release nutrients and agricultural chemicals slowly and sustainably, providing crops with precise doses. This also protects plants and improves disease management. Furthermore, biosensors can detect the presence of pesticides in crops, aiding in informed decision-making **(Siyari & Jabali, 2023)**.

Smart Greenhouses: Greenhouse farming is a systematic approach that helps improve the productivity of vegetables, fruits, and other crops while maintaining environmental standards. This is achieved through the design of smart greenhouses with the help of the Internet of Things (IoT). These greenhouses intelligently monitor and control the climate, eliminating the need for manual intervention. Various sensors are used to measure environmental parameters. IoT sensors provide information on light, pressure, humidity, and temperature levels. These sensors can automatically control actuators to open windows, turn on lights, control the heater, and operate the fan, all via a Wi-Fi signal **(Sayari and Jabali, 2023)**.

Digital Transaction Technology: Blockchain* is a distributed ledger technology that forms the basis of cryptocurrencies. By securing digital transactions and maintaining records, it facilitates product tracking for regulators throughout the supply chain. It allows for efficient monitoring of even the smallest transactions in farms, warehouses, or factories, and the transfer of details across the entire supply chain when combined with the Internet of Things (IoT). Furthermore, it enables the tracking of contaminated food and the identification of affected products during contamination incidents. It also reduces waste by pinpointing supply chain bottlenecks that lead to food spoilage. This transparent system helps curb food fraud, especially with the increasing consumer demand for organic and non-GMO foods **(de Clercq *et al.*, 2018)**.

Remote sensing: This helps farmers monitor crops through analytical dashboards to evaluate crops by tracking changes in shape, size, light, humidity, and temperature—in short, the overall climate. It provides advice and guidance on suitable crop types, analyzes soil quality by selecting appropriate fertilizers, identifies dry areas in the field, analyzes soil drainage capacity, and adjusts irrigation levels. It also provides warnings to farmers to prevent plant diseases. Data is collected periodically within a precise system for storing, analyzing, and retrieving information, which helps in making optimal decisions in a timely manner **(Siyari & Jabali, 2023)**.

Conclusion

Carbon smart agriculture aims to provide modern sustainable agricultural practices and transactions and provide best practices for all agricultural transactions from smart irrigation, controlled fertilization, flexible pest control, and following modern agricultural systems such as hydroponics, soilless agriculture, vertical agriculture, marketing services, and veterinary services in animal, poultry and fish production. It also provides marketing services to small farmers and the best sources for obtaining production requirements from seeds, equipment, and raw materials. It also works on the possibility of direct electronic communication with experts through voice and video calls, in addition to the possibility of exchanging messages and pictures between experts and the farmers' audience.

Carbon Smart Agriculture is essential for building climate-resilient, productive, and sustainable food systems. It offers a pathway to carbon neutrality while improving food security, soil health, and farmer livelihoods.

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الزراعة الذكية من حيث الكربون لتحقيق الاستدامة الزراعية ـ مراجعة

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الملخص

تُعدّ الزراعة الذكية كربونيا نهجاً مثالياً للتعامل مع تغير المناخ، وقد أصبحت واقعاً ملموساً، إذ تلعب دوراً هاماً في الحدّ من آثار تغير المناخ على القطاع الزراعي، كونها أسلوباً زراعياً جديداً يوجّه التغييرات اللازمة في النظم الزراعية لتحقيق أعلى مستوى ممكن من الأمن الغذائي، مع مراعاة الموارد الطبيعية الزراعية وخفض انبعاثات الكربون إلى أدنى مستوى ممكن. وقد اتجه العالم نحو تطوير أساليب زراعية عملية من خلال جعلها أكثر اعتماداً على التقنيات التكنولوجية الحديثة، وتعزيز قدرتها على التكيف مع تغير المناخ وتلبية الطلب المتزايد على الغذاء لتلبية احتياجات النمو السكاني، وهو ما يُعرف بالزراعة الذكية كربونيا. وقد برز مصطلح الزراعة الذكية كأحد نتائج الثورة التكنولوجية الرابعة، حيث تمّ توظيف التقنيات الحاسوبية، وأجهزة الاستشعار عن بُعد، والآلات التي تعمل عن بُعد، وغيرها من الأدوات والتقنيات الحديثة لزيادة إنتاجية وجودة المحاصيل الزراعية، ومقاومة تغير المناخ من خلال ممارسات زراعية ذكية مرنة تتكيف مع تغير المناخ. آليات ومعايير التحول لتطبيق نهج الزراعة الذكية مناخياً وتهدف الورقة العلمية الى التعرف على منهج الزراعة كربونيا وسبل تحقيق التنمية الزراعية المستدامة من خلال تطبيق منهج ومعاملات وممارسات الزراعة الذكية كربونيا.

الكلمات المفتاحية: الزراعة الذكية كربونيا، تغير المناخ، الاستدامة الزراعية.