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Adoption of Internet of Things (IoT) in Smart Farm Management: Implications for Sustainable Agriculture in Iraq

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Abstract

The Internet of Things (IoT) is revolutionizing agriculture by providing real-time data and insights to optimize farming processes. In Iraq, agriculture plays a critical role in the economy, yet the sector faces challenges such as inefficiency, water scarcity, and low productivity. Despite global advancements in IoT-based smart farming, adoption in Iraq remains limited.

The agricultural sector in Iraq suffers from outdated practices, insufficient technological infrastructure, and a lack of awareness about modern farming techniques. Additionally, high costs of IoT implementation and limited expertise exacerbate the issue, preventing farmers from leveraging IoT solutions to enhance productivity and sustainability.

This research explores the adoption of IoT technologies in Iraq’s agricultural sector. It aims to: 1-Analyze how IoT can address agricultural inefficiencies in Iraq. 2-Evaluate the potential benefits and challenges of implementing IoT in the country’s farms. 3-Offer actionable recommendations for integrating IoT into agricultural practices sustainably.

The study reveals that IoT adoption can significantly improve resource management, reduce costs, and enhance yields. Specific benefits include optimized water usage, reduced pesticide application, and better disease management. However, barriers such as high initial costs, lack of expertise, and data privacy concerns hinder widespread adoption.

Keywords:Smart Farm Management, Internet of Things, Agriculture, Environment.

1. Introduction

The need for using the Internet of Things (IoT) in a smart farm is unquestionable because it creates a platform to improve agricultural production processes. This permits stakeholders to perceive the best practices by processing data about farms and yield value (Dhanaraju et al.2022). Agricultural efficiency, productivity, and agribusiness opportunities are the main interests of IoT and have very interesting implications (Lezoche et al.2020). Furthermore, the main objective of this paper is to analyze how the application of the concept of IoT can help solve some of the challenges facing the development of the agricultural sector in Iraq, which is unfortunately getting worse. The application can offer a solution for transforming the agricultural sector in Iraq (Saleh, 2020).

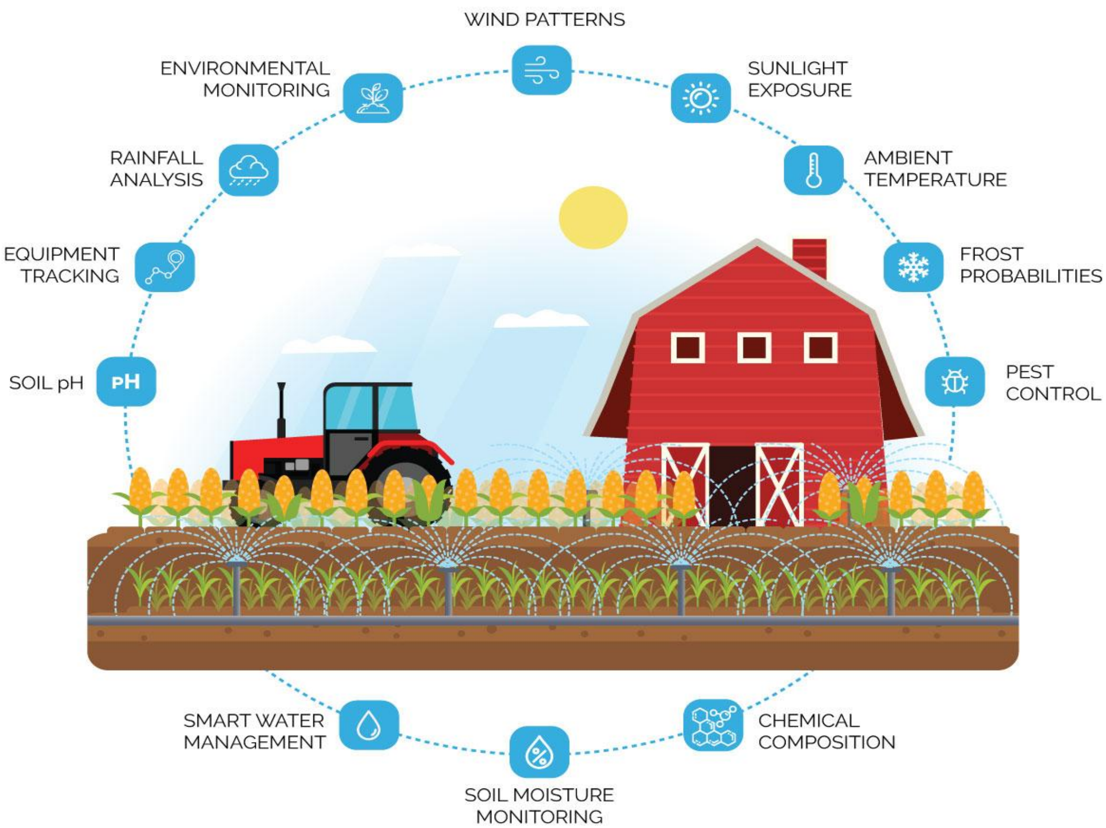
Smart farming or modern farming has been an idea for many years before it was named Farmers 4.0. The concept has involved a paradigm that aims to reformulate farming, not just in terms of technologies, but also in terms of ecosystems in which farmers, food processors, researchers, agribusiness stakeholders, and others have to stay connected (Javaid et al.2022). IoT supports helpful data for smartness, managed, value-added agricultural practices. Smart farming, besides its efficiency, has a function to conserve the use of natural resources and environmentally friendly inputs to meet the increasing demand for agricultural products due to the rising world population. Despite agricultural productivity growth, today the world's food supply is threatened by a number of factors, especially environmental changes. Countries in the world need to secure their agricultural sector in a sustainable manner (Dhanaraju et al.2022). This commitment exists in the goal of the 2030 Agenda, among others, to ensure sustainable agricultural production systems. Thus, in the face of complex global challenges, it requires the involvement of all parties, especially among stakeholders within the agricultural sector, toward greater development based on IoT solutions (Shahmohamadloo et al.2022).

2. Background of IoT in Agriculture

The Internet of Things (IoT) is essentially a network of devices fitted with sensors, software, or other technologies that enable them to connect and exchange data with other systems, software, and devices. Each device or thing on the IoT is fundamentally a system connected with others, often with little human intervention (Kopetz and Steiner2022). Consequently, IoT in agriculture is essentially an interrelated system of things – whether machines, humans, or IT systems – that influence one another and are based on three main components: connectivity, data collection and analysis, and real-time representation. Such components help farmers produce more food more efficiently, with fewer resources and a reduced environmental impact (Bhutta & Ahmad, 2021). The components result in the creation of digital ecosystems that support the service structure of future smart farms.As depicted in Figure 1.

The adoption of precision techniques on a large scale, leading to smart farm management systems, can enhance agricultural sustainability – which is particularly important to emerging economies. IoT systems enable the gathering of substantial amounts of farm data by low-cost automatic sensors as well as various manual data entry points (Karunathilake et al., 2023). These systems allow farmers to make real-time decisions and gradually improve their production systems based on data patterns specifically valid for their farm. This added value presents a wide range of benefits. Primarily, by using precision farming techniques, the amount of water, fertilizers, and pesticides used by farmers can possibly be reduced, with concomitant savings in outlays and water usage. However, IoT entails some major challenges, essentially rooted in the interaction between human behavior and technology: there is eagerness for technology, but at the same time, impending resistance (Monteiro et al., 2021). Secondly, cost – an initial outlay is a starting point just for the base station of one technology, before adding in other packages or software updates. With IoT technologies constantly changing and improving, users must invest in continuous and possibly expensive – technology upgrades (Dhanaraju et al.2022)As depicted in Figure 1.

Figure 1: Smart Farming Technologies: Enhancing Agricultural Efficiency and Sustainability through IoT and AI



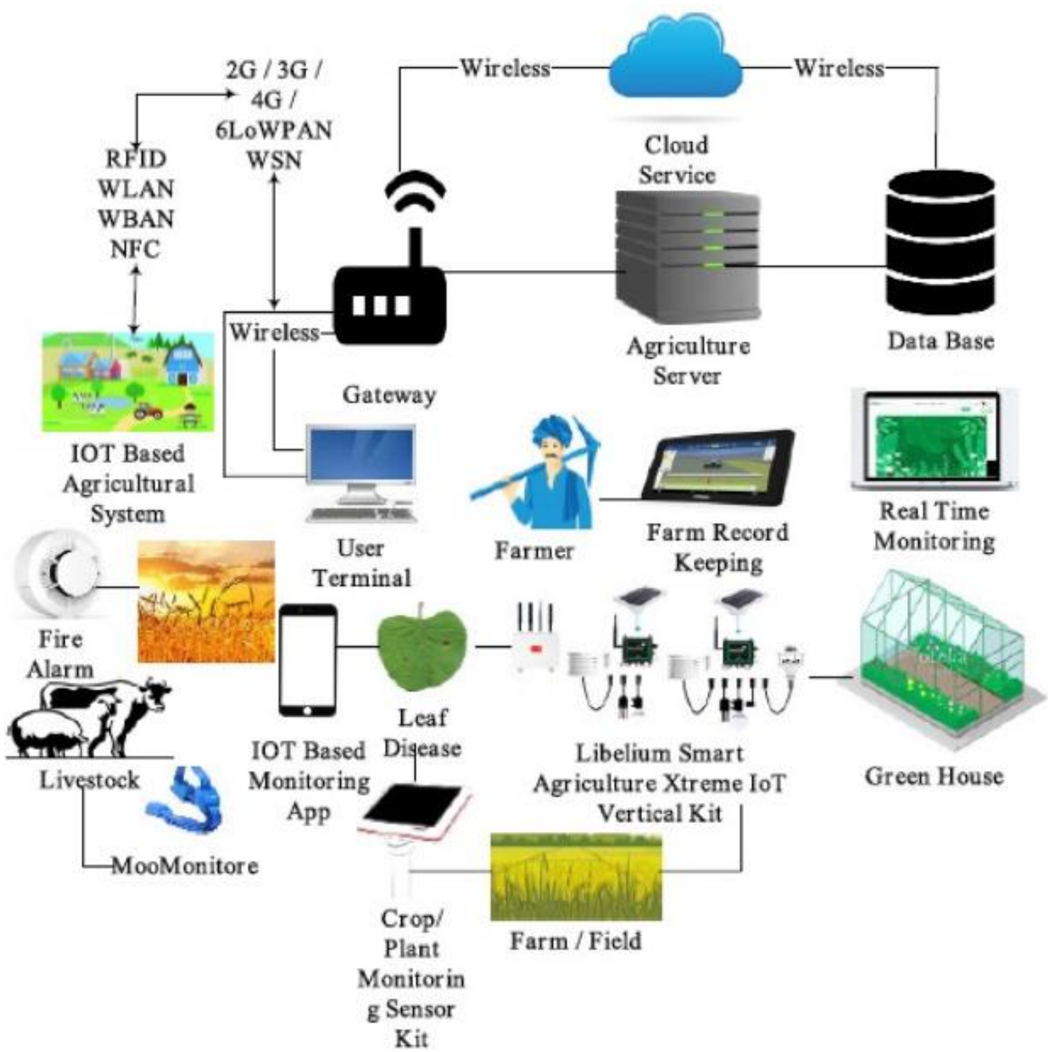
Source: TEKTELIC. (2024).

2.1. Definition and Components of IoT

1. Background In this subsection, a detailed definition of the Internet of Things (IoT) is provided, specifically focusing on its application in agriculture. It breaks down the key components of IoT, including sensors, connectivity, data processing, and user interface (Boursianis et al.2022). The section explains how these components interact to enable real-time monitoring and automation in farming practices. It also discusses the significance of each component in improving operational efficiency and resource management. By illustrating these elements, the subsection emphasizes the technological foundation necessary for effective smart farming (Javaid et al.2022). Additionally, it explores various IoT devices that may be used in agriculture, ranging from soil moisture sensors to climate monitoring systems. This explanation enhances the reader's understanding of the capabilities that IoT can bring to agriculture. The straightforward definition and description serve to clarify any misconceptions surrounding IoT technologies in farming. Smart farming is an innovative approach to sustainable agriculture based on Information and Communication Technologies (ICT), especially the Internet of Things (IoT) (Dhanaraju et al.2022). The conventional agricultural practices can be integrated with IoT to enhance efficiency, productivity, profitability, and sustainability. IoT is a core technology behind the smart ecosystems that would connect smart industries of the future. Thus, IoT can be viewed as network systems consisting of essential components, such as sensors or devices that are spread over large geographic areas to collect real-time data or measurements (Singh et al., 2021). The IoT devices are further connected to the Internet to share the data with stakeholders or application software platforms. Therefore, the

IoT sends the data to the cloud or to other connected devices, where the data is processed, stored, managed, and visualized. Thus, IoT services are characterized by four main components: devices or sensors, connectivity, data processing or analysis, and user interface (Gupta and Quamara2020). Sustainable agriculture is a global field that faces immense challenges. A range of IoT devices can be used to improve, automate, or optimize agricultural practices. Each IoT device might capture different types of data or serve different purposes. For example, IoT can capture soil moisture, temperature, acidity, or even electrical conductivity across a vast area (Kassim, 2020). Additionally, IoT devices may capture climate conditions, such as wind direction, ground or cloud temperatures, humidity, rainfall, UV radiation, nitrogen oxides, acid rain, ozone, and carbon monoxide, and provide a warning for imminent danger, see Figure 2. They may even monitor animal health and welfare. There are already numerous applications of IoT devices in agriculture, with new technologies being developed and integrated into the agricultural sector. It is important to define the IoT, for there are some misconceptions around its features (Liang and Shah, 2023).

Figure 2: The Smart Farming Trends



Source: Mahbub, M. (2020).

At the field level, sensor networks collect and transmit data about the environmental conditions, soil, or crop physiology that is then processed offsite by connected hardware and software to create recommendations that are sent to clients by mobile phones and other handheld computers. These technologies are at the forefront of agriculture's digital revolution. By doing so, stakeholders can obtain real-time information about the agro-ecosystems (Sanjeevi et al.2020). The technologies do not use the cloud, mobile apps, or wireless internet services. Though IoT makes use of the cloud, wireless communication, and other web/internet technologies, it can work offline and can be implemented without the Internet. Devices are normally implemented in collecting data. Each one of them can measure a certain parameter related to the system operated. They can simply sense data from what surrounds or interacts with them and send this data into another system for subsequent automatic decision-making, taking feedback, or the ability to automatically control (Mouha, 2021).

2.2. Benefits and Challenges of IoT Adoption in Agriculture

2.2.1. Benefits of IoT Adoption in Agriculture Interest in IoT applications in farming is due to the wide range of potential benefits for the farming sector across the world and at different scales of farming practices (Kim et al., 2020). IoT systems often translate farm data both in real-time and not to information that connects farming activities and management to improve value chains in terms of food security, optimizing human labor, and conserving resources. As a guiding principle, IoT applications in farming can increase efficiency and production to maintain and/or increase yields; reduce costs by improving information use and resource management; and decrease environmental impacts (Dhanaraju et al.2022). For efficiency improvements, IoT and data analytics can allocate agricultural inputs such as irrigation, fertilizer, or feed to precisely meet their requirements, and monitor livestock or crops to more accurately detect diseases, pests, nutrition, and stress conditions, weather, and soil (Dhanaraju et al.2022).

However, until now, the widespread adoption of IoT in agriculture has been modest. There are a number of reasons for this, many of which were identified in the agri-food community and are linked with the adoption of new technologies and change (Sinha & Dhanalakshmi, 2022). This includes reluctance from farmers to leave their comfort zones due to a fear of the unknown and a desire to avoid risk. Because some IoT solutions require a sizable up-front investment, they may be the thing that breaks an already shaky bank and land the farmer in financial ruin. The adoption of IoT technology is not without challenges (Nižetić et al.2020). These challenges include the cost of the IoT devices, the lack of digital skills, data privacy, and the lack of IoT expertise, which is considered one of the most critical challenges. Several months of technical skills training and support are provided to new IoT users during the pilot training to support them in becoming familiar with the new system (Idoje et al., 2021). Data privacy and ownership are two significant concerns for producers when it comes to the use of any precision agriculture technology, including IoT. Data that has been accurately captured and interpreted does not belong only to the farmer/user; it can be used in other commercial ways, such as helping develop new products. In the context of precision agriculture, management support services may use the data that IoT applications have collected from and about farmers for a range of purposes that includes farmer support, but also supported market analysis, decision-making applications, new service development, and even entrepreneurial farming (Chanal & Kakkasageri, 2020). The most significant barriers faced in adopting digital technologies came from the technical category (i.e., lack of knowledge and competencies and lack of infrastructure), followed by attitudinal and financial barriers (Ullah et al.2021).

3. Smart Farm Management Systems

Smart farm management systems have made a revolution by integrating Internet of Things technologies in farming to optimize agricultural processes. These systems are comprised of different technologies to manage a farm by developing several modern techniques and marketing strategies, which makes it possible to optimize farming parameters, maximize yields, and maintain crop quality (Boursianis et al.2022). A smart farm management system consists of several components, such as a control center with monitoring ability, automation systems, a decision support system, a data analytics platform, and a mobile application for farmers (Mahbub, 2020). Automation tools are the main part of a smart farm application system, which includes numerous agricultural applications like precision agriculture, natural resource management, dairy farm systems, aquaculture systems, and more. Data analytics platforms are software that can help farmers easily use these vast amounts of information to make informed decisions, while mobile applications make managing the day-to-day aspects of farming more efficient and coordinated (Javaid et al.2022).

Many different methodologies have been developed for smart farming, which can be used to develop systems taking into account different sections, such as natural resources, analysis mechanisms, and the scale of the environment. Natural resources-based smart farming systems rely on the information acquired from the arrangement of sensors and provide information such as soil conditions, weather, weeds, and pests (Chukkapalli et al.2020). These systems can also be used to reduce environmental emissions into the atmosphere, energy usage, and increase product yields. For example, some types of data like wetting schedule, use of water, growth density, relative humidity, and soil moisture are collected by using sensors and an automated irrigation system to enhance the productivity of cucumber cultivation with chemical fertilization in greenhouses. In a managed environment, such as greenhouses, flowering date and time of inner-plot soil temperature is an important variable that affects the rooting time (Sovacool et al.2021). The better the rooting time, the more it will improve the rooting percentage. Horticultural robots with sensors and software, as well as automated systems, are able to support the management of these parameters to enhance productivity and improve the quality of crops in greenhouses and storage facilities (Singh et al.2022).

3.1. Key Components and Technologies

Increased implementation of advanced farm machinery and ICT systems has resulted in a range of new tools being made available to farmers and farm managers. These include machine and crop sensors, drones, field robots, and satellite imagery (Danda, 2024). Information derived from these technology implementations and other data sources is processed and analyzed using one or more computers running appropriate algorithms and agronomic models. Information on recommended actions or prescription maps, relevant for the management of the particular farm attribute, is then generated and delivered to the appropriate location and deployed either on-board a machine or tractor or conveyed separately, for example, by a mobile phone or computer, to an operator, contractor, or cropping advisor (Rehman et al.2022). These tools generally fall into the broader categories of:

* Sensors: on-board machinery, crop, environment
* Drones: aircraft fitted with multi-spectral/RGB cameras for field inspection
* Field robotic vehicles: used for compact sections of the farm for a variety of tasks

* Satellite heritage: satellite images are developed at different spatial resolutions and in different frequency bands, particularly useful for broad-scale farm infrastructure, soil zone types, and boundaries
* Computer-based machinery guidance systems and software: for planning, management, and survey of farm activities (Kucharczyk & Hugenholtz, 2021)(Hussein et al.2021)(Yeong et al., 2021). Implementation of these systems is changing the landscape of agriculture, ensuring precision agriculture outcomes. Many of these tools are employed to provide real-time in-season recommendations. The benefits of 'real-time' advice have been well established in scientific literature and the Australian cropping context (Hamid et al.2021). For inputs, the ability to apply deficit or surplus applications of plant protective products, such as fertilizer, chemicals, and water, results in a high likelihood of profit. This also reduces risks of environmental pollution. Many of these in-crop sensors and related tools are used in variable rate farming based on relevant prescription maps (Chivenge et al.2022).

3.2. Integration of IoT in Farming Operations

IoT is influencing the agricultural domain, particularly in improving farming operations at various development levels. Practical integration of IoT is depicted in the literature, including diverse devices designed to function efficiently in large-scale farming operations. This incorporates stock control such as cattle, water systems, and energy consumption (Boursianis et al.2022). The provision of advanced irrigation from the Lolayetta lands network aligns with this line of thinking. Furthermore, other monitoring applications have been developed for precision agriculture. The decision support system for monitoring soil moisture levels, pH, as well as electric conductivity, weather conditions, air temperature, humidity, onset of rain, wind direction, speed, and rainfall has been developed for the WIC-EO multi-connector (Zhai et al.2020). The RHT sensor was designed using a microcontroller and connected to the Internet via Wi-Fi and web data management (Santos et al.2023).

The LoRa protocol, which collects and analyzes real-time temperature, humidity, water conditions, and others with a wide range of TSRs, is also used to monitor water quality in aquaculture. Numerous applications employing IoT have been presented to efficiently manage different crops, including horticultural plants and grains (Sendra et al.2023). Diverse devices are used, including sensors connected to the Internet via wireless technologies capable of transmitting live data to producers and managers. Recently, vegetable farmers in the villages engaged in the project, adopting various IoT technologies targeting the improvement of crop productivity. Integrated designs that encompass off-the-shelf wireless sensors can be used to monitor variables within farms, such as soil moisture content and saline water availability, gate operation, and vehicles or people counting have also been reported. The sensors communicate with the established LoRa network, and data are consolidated on a cloud-based management system for user access. Environmental data imports to the management system and services alarms based on predefined threshold values (Dhanaraju et al.2022). Farmers can access this real-time data from anywhere using the Internet through their mobile devices, iPad, or computer. Organizing the real-time data and information in an easy way to understand for the end user was a driving goal in the design of the system (Liang and Shah2023).

Furthermore, three types of low-cost sensors are employed and strategically installed at the farms in flexible designs based on their needs. By doing so, farmers can deploy a tailored approach to the management of crop consignment with immediate reactions to environmental influences. Other activities of farmers to handle their farms, such as analyzing the weather, soil, and other conditions to make decisions and take actions, have been made very simple by the developed management system (Soussi et al., 2024). Comprehensive information that relates to the likelihood of farm planning and human error minimization can be employed with the analytic report. Additionally, it was argued that wireless irrigation sensor data integration with wireless soil sensors from other companies was undertaken, but only offered weather stations. Further demonstrations showed how a seamless Bluetooth-integrated digital flow meter continuously measures meter connection quality, wireless, and data availability while irrigating a field (Ambildhuke and Banik2022). Emerging issues in agricultural technology are revealing that water-use efficiency does not strictly relate to measuring soil or plant moisture. However, it was reported that by integrating the flow meter data with weather stations and SAR-based evapotranspiration estimates, farmers examine real-time information and make proactive decisions (Liang and Shah2023).

4. Case Studies of IoT Adoption in Agriculture

4. Case Studies of IoT Adoption in Agriculture: This initial case study on IoT in Egypt showcases the use of low-cost data validation devices and ZigBee sensors in open-field agriculture to collect climate, soil, and leaf wetness data that are sent to data visualization dashboards (Yin et al., 2021). These have been in use since the late 1990s to help farmers in Galicia better manage grape production. In the sheep sector, commercial lambs are known to have different feed efficiencies; identifying and classifying that feed conversion, especially on intensive diets, has been problematic (Ellison et al.2022). IoT devices in all the examples discussed are low cost, and indeed the combined technical and electronic components typically do not amount to over 30%. A smart farm package has been unveiled for Australian broadacre farmers to optimize worker and machine efficiency through enhanced communication and decision-making on the farm (Newton et al., 2020). A project utilized an IoT platform to couple high-accuracy analytics, automation, machinery, and biological data to deliver real-time recommendations to producers, especially targeted around adverse events (Rane et al.2024).

In the UK, a project designed to integrate best practices has been growing and is now called FieldBazaar. A follow-up discussion covers the practical application of such technologies and provides case studies of IoT in agriculture. Three of the case studies involve viticulture, and two are in Pakistan and Iraq, with the rest as far afield as Colombia (Alhasan et al.2022). Providing nine case studies from different world regions adds depth to the understanding of challenges and variations in types of produce and technologies (Bereczki & Kárpáti, 2021). IoT case studies in Iraq: platforms have been developing IoT applications worldwide in its application of precision and smart agriculture concepts and technologies. The Kurdistan Region of Iraq and the rest of Iraq depend on both public and private drinking water resources. Water use in agriculture is incredibly high in the Kurdistan Region and the rest of Iraq, whereby the SmartAgri-IoT can provide more pragmatic guidelines when it comes to water use and ensure that only the optimal irrigation amount and frequency are used in agricultural lands. It was found that Arab varieties receive advice via smartphone in the city of Missan, which helped farmers during the COVID-19 curfew (Tahir & Harun, 2022; Abdulrahman, 2020). There is a growing interest in lifestyle farming, with international farmers growing crops such as lavender and ostriches in the region. The SmartAgri-IoT can be utilized for such farms, whereby IoT devices can be used by mobile telecom operators (Zwarts et al., 2023).

4.1. Global Examples

Wheat and Dairy Farming in Alert Tasmania: Peter and Bev Vonarx operate a 2,000-hectare farm in north-west Tasmania, which is home to a herd of 1,000 pasture-raised cows. Weather is a major challenge in the region – dry summers, wind, and rain – extensive tracking of weather using a set of IoT sensors to develop land management practices and improve cow health (Neethirajan & Kemp, 2021). Irrigation and water application control also contribute to the overall improvement in farm performance. Data Stream Farming: Allan Giffard operates a 2,500-hectare property near Griffith in the New South Wales irrigated region (Abioye et al.2020). Mildura's main climate challenges are hot temperatures, wind, and the risk of frost. It is with this in mind that the farm uses a series of technologies that provide data streams, including remotely piloted aircraft, to undertake aspects of crop management such as water and nutrient application. Despite only very recently taking the farm up as an interoperable digital farm, the return from several projects substantiates the value of IoT technology from a farm sector worth A$921 million per annum. The transferability of the dairy and cropping sensor technology from Tasmania, Mildura, and Goulburn, although linked to a related agricultural sector with similar off-farm requirements of quality assured producers, not forgetting the potential market value, would be significantly lower than that of the sensors in the wine industry. Compared with Chinese agriculture, which adopted almost the same number of IoT sensors, the technology solutions are better and therefore more expensive. Other Chinese agriculture technology has also proven to have poor on-farm uptake because the solutions were designed on an unrealistic model and were beyond the affordability of most farmers. Notwithstanding the systems across the world that display multiple sensors for weather prediction, evidence that purchasing a weather station in 2015 avoided a $700,000 loss in productivity, but also avoided the loss of 2,900 cattle as predicted by the model. Large percentage changes in on-farm decision making as a result of real-time weather data responsive tools. It is not only in large agriculture that the IoT has demonstrated ROI capability; clearly, in the wine sector, significant uptake has displayed that value. According to a single use case documented, a deployment of IoT has helped to deliver a $134,000 to $240,000 per annum increase in gross margin.

4.2. Iraq-specific Examples

4.2. Iraq-specific Examples. Despite the reported lack of studies, there are examples from Iraq showing that local farming communities are adopting and integrating IoT technologies to improve their farm and production systems. One example of using IoT in agricultural fields is to assess the crop yield associated with the production system (Allawi & Al-Jazaeri, 2023). Cucumber yield has significantly increased by 7–23% by using a sprinkler irrigation system. Although such an assessment does not cover the full stack and all environmental, social, and economic Agri-IoT aspects, it gives an idea of how using some technologies on the farm could enhance the productivity of a particular single plant. The more examples of using IoT in agriculture are not well published. This section presents successful implementation of IoT in agriculture to support more farm management and sustainability of agricultural processes (Cui et al., 2020).

The Ministry of Agriculture and Irrigation, in collaboration with the private sector, conducted some projects in terms of smart villages under precision agriculture in different cities of Iraq, such as Zurbatiya and Badra. The project contains the following characteristics: connecting devices and gathering information, including temperature, humidity, carbon monoxide, and other pollutants; controlling and managing agricultural production; managing the process of measuring fields and conducting analysis for all agricultural tests, such as the content of macronutrients, micronutrients, and pH values; sharing data to make decisions; reducing water through precision irrigation, which helps in water management applications and measuring the conductivity of soil and agricultural irrigation practices. In addition, another project using IoT technologies was established in Najaf governorate, which consists of installing smart water meters in the city and in the villages (Ali and

Ali2023). The purpose of these projects is to reduce the waste of drinking water, especially in this period when most of the populated cities in Iraq are subjected to a severe lack of water.

5. Implications for Sustainable Agriculture in Iraq

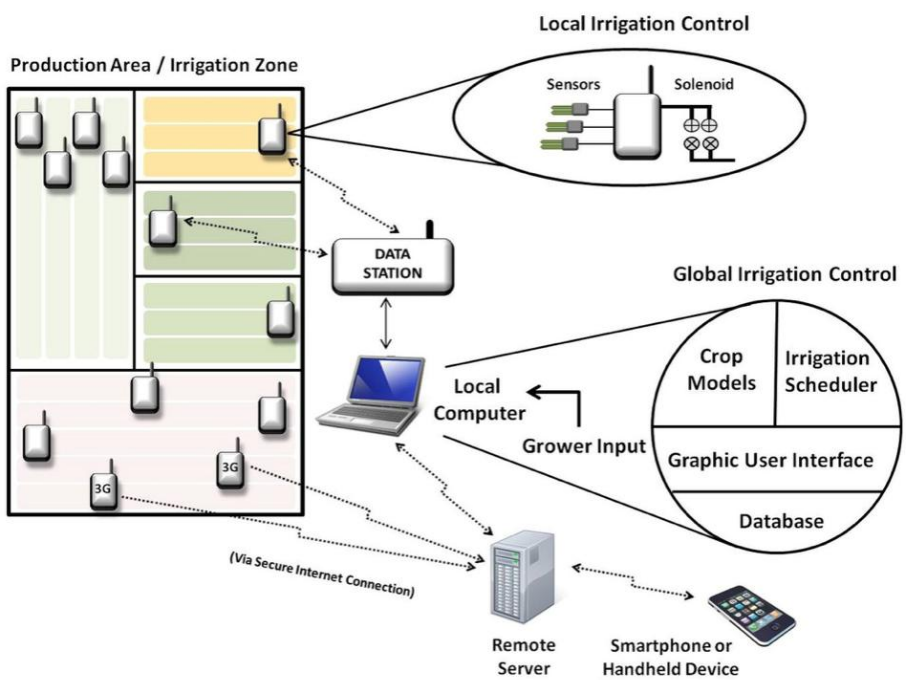
5.1 Improving Environmental Conditions

IoT technologies allow for sound and efficient natural resource management, which in turn produces less environmental degradation. Through big data collection and analysis, farmers can figure out the best solutions to protect the environment and natural resources (Akhigbe et al.2021). An IoT-based approach improves the environmental sustainability of agriculture since farmers can examine variables such as weather conditions and cultivation types. Therefore, it is possible to reduce human pressure on natural resources. For example, reducing pesticides through real-time disinsectization may improve contact between insects and biopesticides; this benefits the environment and is more sustainable over the long term (Haseeb et al., 2020).

5.2 Increasing Economic Growth

The adoption of IoT at any stage of the food chain can reduce costs significantlyas in Figure 3. Improved costs and margins can be achieved by minimizing waste with better quality control, speeding up processes, and using resources more efficiently. The provisioning of collected data to all value chain parties results in reduced overall costs and increased profits per value chain actor (Aamer et al.2021). The increased awareness of all parties in the food chain ultimately results in higher overall income and improved livelihoods. Precision farming is considered to bolster conservation tillage and no-tillage methods that protect and save the most natural resources from degradation (Júnior et al.2024).

Figure 3: Smart Farming System: Sensor and Control Technologies for EnhancedIrrigation Efficiency and Sustainable Production



Source: Smart Farms Home (2024).

Farmers can save up to 20% of the costs of water, fertilizers, chemicals, and up to 10% of the fuel costs used in tractors. These figures translate into euros, just at the level of the company, in a savings range that varies between €50/ha and €85/ha/year, depending on the level of digital technology (Gathala et al.2020).

5.3 Cultural and Social Implications

Enhancing the culture of local farmers can be employed; it allows for regional identity and jungle livelihoods to be exposed. For instance, the emphasis on traditional seafaring, combined with fishing cultures, has consolidated prosperity, earning a place in Intangible Cultural Heritage. Some small-scale IoT technologies could, in the same way, validate the sustainable benefits related to mountain olive selection or fruit farming (Dhanaraju et al.2022). Convergent research is scarce because few measurements, procedures, or evaluation systems combine environmental, economic, and social dimensions. Focusing on the interactions between those three areas is regarded as an innovative contribution to the evaluation of IoT technology in agriculture. Our research aims to evaluate the second era of IoT adoption and the use of technologies in terms of sustainability factors, effectiveness, and supervision (Raj et al.2021). Collecting data in the three analyzed areas, lower production costs are possible for the entire agri-food market, enhancing economic growth as a justified return on investment (Zhao et al., 2021).

6.1. Environmental Impact

6.1. - Environmental Impact

One facet of global concerns is the environmental impact of smart farming in terms of soil, water, nutrients, and ecosystems. Adoption of IoT in farming can ameliorate its environmental footprint. It can reduce waste related to overuse of resources, mitigate emissions obtained from resource wastefulness, optimize usage of farm inputs like seeds and fertilizers, reduce wastefulness, and minimize negative externalities (Lakhiar et al.2024). The main ecological impacts in farming are related to using clean water, soil nutrients, and land area to grow crops. Inefficient use has major repercussions on soil sustainability and the environment; reductions in resource usage can have positive effects. Freshwater withdrawals globally have more than doubled since World War II (Kaushal et al.2021).

Water conservation: Several environmental disadvantages can be diminished or prevented through IoT services for water reduction from IoT technologies. IoT services for farmers can provide detailed water requirements with respect to crop growth and can reveal excess moisture in soils. These can minimize damage due to over-watering, allow soil drying before harvest, and ensure crop yield potentials are not limited due to water logging. Enhanced soil quality: Imports from the application of IoT to smart farming contribute to the use of sustainable intensification practices in farming, which include reductions in soil chemical runoff, soil water holding, and nutrient supply (Tang et al.2021). Adoption of IoT usage in farming practice has significantly decreased soil nutrient and agricultural chemical runoff and wastage in potential fertilizers. IoT can provide a more precise history of feed uptake by crops, which in turn can give a precise indication of residual nutrients. This can reduce the amount of runoff from farm fields into water supply systems and can contribute to lessening water treatment costs. Policy requires the promotion of agricultural practices that contribute to sustainable farming and minimize water pollution from chemicals. Biodiversity: IoT usage practiced as part of cropping and farming systems in commercial agriculture has insufficiently been influenced to make observations about environmental effects (Xia et al.2020). Those instances of land use types generally enhance the landscape's ecological function. For example, reduced tilling and use of permanent, internal grassed lands integrate with agendas for supporting soil conservation and enhancing wildlife habitat. Agricultural technology in the development of machinery and techniques used only in premium cropping enterprises does not incorporate any of these aspects into machinery specifications. Proposed practices have three primary environmental advantages: reduced residue trapping due to less intense tillage, minimized fertilizers and nutrient release, and minimized energy usage and emissions by farmers (Da et al.2021). Farmers using these practices are assumed to be offering some 'ecosystem services' to the broader community. Medium-term indicators of the success of sustainability ecosystem services depend on environmental factors. Calls will therefore only be able to express benefits on a case-by-case basis. Farmers are receiving machinery and system equipment in the expectation of issuers delivering a novel system with agricultural benefits (Tamburini et al.2020).

6.2. Economic Benefits

Does the adoption of IoT benefit farmers financially? Several studies have suggested that farmers do indeed experience significant cost reductions and efficiency gains through the adoption of IoT. This can occur when the use of IoT technology leads to (i) resource savings through the development of smart inputs that are used only as required; (ii) cost savings on inputs, labor, and energy; and (iii) increased yields. Potential savings and efficiencies include reducing water use by 25%, reducing fertilizer use and costs by 25%, reducing drinking water for dairy cows by 60%, and reducing the area devoted to chickpeas by 28%, while maintaining yields. All of these case studies have employed IoT technologies to do so (Raj et al.2021).

Empirical evidence supporting the farm-level benefits of IoT is provided in the case study literature. A survey of pumpkin growers found that IoT emitters reduced water costs by about 5%, with a 1% increase in crop yield. The respondents confirmed that IoT emitters are a good alternative for the application of precise irrigation systems, as they save time and space. The potential reduction in planting area via the use of the drip-irrigation system with IoT would increase farmer profit and, in turn, provide sustainable income for the farmers (Shabbir et al.2020). The linchpin of a zero farming approach is the cultivation of increasingly nutrient-rich, high-value crops using field-level IoT technologies like innovative internet-connected fish-feeding products that can optimize feeding post-harvest, drones, and surveillance systems to monitor crops, fish feeding, water temperature, and salinity management software. The adoption of IoT in working farms underscores the potential for high yields and profits. Economies of scale may also be realized if successful IoT in working and innovative farms acts as a beacon to those beginning IoT adoption (Rajabzadeh & Fatorachian, 2023). The increase in local fish feed demand and production in supporting farmers' innovation contributes directly and indirectly to job creation. Each factor mentioned in the zero farming diagram contributes to solving major challenges in agriculture, contributing not just to food security but, by extension, to regional and country development. This is supported by development priorities and sustainable development goals for many countries, and consequently, the prioritization of investment in technologies and business models that facilitate transformation is necessary (Nasr-Allah et al.2020).

6.3. Social Implications

Opportunities. Integrating IoT technology into agriculture holds both promising opportunities for farmers and barriers to effective adoption. IoT technology can empower farmers by providing direct control over data flows within an intelligent digital environment. They can connect with various digital data services through the use of IoT to support and enhance their decision-making power, create efficiency, and produce sustainable output (Torky & Hassanein, 2020) As such, perhaps more importantly, a digitalization pathway geared towards smart management systems in the digital agricultural age will empower farmers in the socio-economic and techno-economic relationships representing the triple win for entrepreneurial savvy and future social welfare. For instance, the insights from the household survey show that the potential high precision technology calibrated through IoT-based data acquisition in paddies could be a tool to direct people living in relatively small-scale, marginal, and even farm-based livelihoods that require seasonal jobs in multiple occupation systems producing sufficient value at the end (Büyüközkan & Uztürk, 2024).

Challenges. The streamlined flow of real-time big data created as a result of these technologies has implications for both social and environmental systems. Farmers, particularly within marginal and farm-based livelihoods, face notable challenges that may limit their ability to adopt IoT technologies. One key challenge is the digital divide, where access to technology is not readily available or is cost-prohibitive (Sharma et al., 2022). This not only includes limitations in technology access and cost of use but also a lack of training and time to learn how to effectively integrate and use new technological resources within these systems. Several community-based initiatives aim to reduce and minimize the barriers that might limit the inclusivity and spread of smart management technologies. Building trust and reducing resistance within communities is central to the development and acceptance of smart technologies. Within the data sphere, ensuring privacy with the accountability and verification of the identity and credibility of persons involved in controlling data runs as a common underlying principle. Ideally, data governance involves consent as the central mechanism for enabling data use (Alabdali et al., 2023).

As the role of technologies in agriculture transitions from primary production to data acquisition and integrative systems management, new skills will need to be developed to engage individuals and farmers. Community-based and farmer-to-farmer educational programs and demonstration assessments are therefore crucial for facilitating the uptake and adoption of these platforms. As development initiatives prompt large-scale change in land use and management practices, it is vital that the implications of such innovations, both beneficial and damaging, are projected into the future. When the implementation of smart farming faces social challenges, such as the question of access, trends of dis-adoption in the digitalization pathway can be expected (Stringer et al.2020). Agricultural digitalization must, therefore, be considered as an advanced technological pathway within a comprehensive systems approach drawing upon data innovation systems. This will necessarily consider the diversity of agro-ecosystem contexts, farmer identities, traditional pathways, and knowledge systems for shaping more desirable futures for tomorrow (Lajoie-O'Malley et al.2020).

7. Challenges and Future Directions

7.1. Barriers for the Adoption of IoT Technologies in Agriculture From an industry perspective, there are eight major potential barriers for the adoption of IoT technologies in agriculture: • High initial investment cost is a barrier; however, recent research shows that, in the long term, industrial actions result in profit. • No technical skills in IT, software development, and data analytics are a challenge. • Resistance towards the use of computers and smartphones is human-related resistance. • The technology has dispelled the rural community from traditional means. • Excessive misuse of social media among the population is also related to people disliking technology. • Data security is an issue due to data confidentiality and the people behind the system who are also at risk. • Technological illiteracy and the presence of generations who are unfamiliar with technology are a problem (Kumar et al.2022).

7.2. Future Directions Future directions in this field should be guided to produce a stand-alone IoT device, which is directly integrated with a traditional sensor. These devices work especially well in maintaining greenhouses and gardens around the country in terms of watering scheduling and temperature control. Additionally, providing extensive information on cultivation by applying Internet of Things (IoT) technologies with an emphasis on production systems that hinge on agro-environment, IoT services for Integrated Pest Management, phytosanitary treatment of growing media, and addressing ash urns and bins in the cultivation environment is essential (Boursianis et al.2022). A comprehensive review of the literature needs to be conducted regarding IoT in agriculture, especially multifunctionality in agriculture, agri-environmental dimensions, consumer choices, behavioral modeling, and trade-off issues in the context of the adoption of Internet of Things applications in sustainable agriculture (Farooq et al., 2020).
Supported by collaborative actions between representatives of the government, IT developers, and experts in the field of agriculture, a vision should be developed to define the ambition from the technical side. Workshops should collect examples of the challenges in the field with verification cases (Mahdad et al.2022). Documentation of stakeholders' needs, challenges, and the way forward should be presented in a report with the intention to pave the way to the local Living Lab. Policymakers, business developers, and investors should explore what's next based on the report and benefit from the outcome of the work package in order to contribute to the development of the local Living Lab (Thees et al., 2020). Even though IoT adoption comes with great benefits, many challenges are still holding back the change in today's smart farming. The trend of IoT adoption has yet to gain the attention of some governments in order to alter the policy framework in these countries. Therefore, it is important to educate unskilled farmers by establishing workshops that involve the workings of IT, software, and data analytics in terms of agricultural applications and related technologies, targeting the communities and media. As part of IoT technology trends, some key future directions might include ongoing core system development since current research is limited due to technological growth in IoT hardware and middleware. Research on middleware operations has been a lynchpin of today's research because of its extensive applications, especially when utilized in smartphones in the region (Karunathilake et al., 2023). In the future, more research should be attempted on IoT data.

8. Conclusion and Recommendations

This article has shown that the adoption of IoT technologies has the potential to critically transform conventional farming practices in Iraq, leading to progress towards a strong, sustainable agricultural sector that can underpin economic and social empowerment. Nevertheless, challenges including inadequate technological infrastructure, the high cost of IoT devices, and the uncertain future of advanced technologies have weakened the uptake rate of IoT in Iraq's agricultural sector. Overcoming these challenges requires not only the technological advancement of IoT devices and sensors, but also a strategic, systematic plan to manage the adoption of IoT in Iraq's agricultural practices. By encouraging this, traditional farmers are likely to find the incentive for adopting IoT in their agricultural activities, and tech companies are able to position them a step ahead in reforming the field of agricultural IoT devices. The adoption of IoT technologies is a cornerstone of various technological trends observed to shape the future of humanity in general, as well as the agricultural sector. These trends are expected to see agricultural practices keep up with the increasing world population and to explore an answer to the triggers of climate change and new diseases that affect plants and animals (Hussein et al.2024). Iraq is one of the countries with a long history in agriculture and has the resources of water, tillable lands, and a good climate, and so it is quite fit for a rapid advancement towards scientific agriculture and sustainable livelihood. The global participation in these scientific trends has not been taken by Iraq; this lack of attention and participation in newly developed technologies, along with the absence of human understanding and knowledge, has made Iraq import agricultural products worth US $6.8 billion from different countries around the world, approximately 75 percent of the country's self-sufficiency requirement. To all stakeholders, a recommendation is required to develop farms, farmers, and those involved in developing software and related applications; they must participate in workshops, conferences, and lectures to exchange ideas and information among themselves. Such business-community boards will help to identify certain problematic areas and develop potential projects of interest to farmers to use IoT technology in Iraq (Wang, 2022). Policymakers need to do more to increase the trust in high-quality IoT devices and to hold talks with various countries to sign technology cooperation agreements.

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