IoT Techniques for Digital Agriculture Monitoring and Soil Nutrients Assessment

IoT Techniques for Digital Agriculture Monitoring and Soil Nutrients Assessment

By

Marina T. Stojanova, Dragutin A. Djukic,
Monika Stojanova and Aziz Şatana

Cambridge
Scholars
Publishing

IoT Techniques for Digital Agriculture Monitoring
and Soil Nutrients Assessment

By Marina T. Stojanova, Dragutin A. Djukic, Monika Stojanova
and Aziz Şatana

This book first published 2025

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library

ISBN: 978-1-0364-4969-8
ISBN (Ebook): 978-1-0364-4970-4

TABLE OF CONTENTS

Preface xi

Chapter I 1
The Role of Digital Agriculture Monitoring System
through IoT-based Techniques

1. Introduction 1

2. Importance of Agricultural Production 2
    2.1. The Vision of Agricultural Development 5

3. Digitalization in Agriculture 7
    3.1. Innovative Technologies in Agriculture that are Used to Digitize
    the Agricultural Enterprise 15
        3.1.1. Cloud Computing (Fog Computing) 15
        3.1.2. Internet of Things (IoT) 18
        3.1.3. Machine Learning 19
        3.1.4. Big Data 21
        3.1.5. Artificial Intelligence (AI) 24
    3.2. Mobile Applications in Smart Agriculture 24
        3.2.1. Cropio 26
        3.2.2. TagItWine 27
        3.2.3. AgroNet 27
        3.2.4. Agrivi 27
        3.2.5. AgriApp 28
        3.2.6. Plantix 28
        3.2.7. Farming Calculator Pro 29
        3.2.8. Organic Gardening 29
    3.3. The Importance of Digital Technology 29
    3.4. The Impact of Digitization on the Agricultural Sector 33
    3.5. The Concept of Smart Agriculture 38
        3.5.1. The Foundations of Smart Agriculture Technology 39
        3.5.2. Analysis of Today's Well-Known Smart
        Agriculture Services 40
            3.5.2.1. Map my Crop 40

3.5.2.2. CropX 40
3.5.2.3. Comparison of Map my Crop and CropX 41
3.6. Potential Economic and Environmental Effects of Digitization and Agriculture 42

4. Current and Future of Agriculture 44

5. Introduction to IoT Systems and Technologies 46
5.1. IoT (Internet of Things) 46
5.2. Advantages and Disadvantages of IoT Technology 50
5.3. Development of the Internet of Things 53
5.4. The impact of the Internet of Things 54
5.5. Savings with the Internet of Things 55
5.6. Architecture of IoT 56
5.6.1. Three-layer Architecture 56
5.6.2. Five-layer Architecture 57
5.6.3. Seven-layer Architecture 59
5.7. Communication models 60
5.7.1. Communication Between Devices (Device-To-Device) 61
5.7.2. Communication between Device and Cloud (Device-To-Cloud) 62
5.7.3. Communication Model Between Device and Router (Device-To-Getaway) 63
5.7.4. Server-side Data Sharing Model (Back-End Data-Sharing) ... 64
5.8. Technologies Supporting IoT 65
5.9. IoT Legislation 71
5.10. Standard Systems of Agricultural IoT 72
5.10.1. Standardization of Agricultural IoT Application System ... 72
5.11. Application of IoT in Agriculture 72

6. Agricultural Drones (Unmanned Aerial Vehicles) 78

7. Farm Management System 81

8. Soil Monitoring System 82
8.1. GPS-based Soil Sampling 82

9. Variable Rate Technology (VRT) 84

10. Monitoring of Livestock and Geogrids 84

11. Precision Agriculture 85
12. Groups of Agricultural Applications 96
12.1. The Structure of IoT in Agriculture 97
12.2. Features of Agricultural IoT 100
12.3. IoT Use Cases in Agriculture 101
12.3.1. Predictive Analytics for Smart Agriculture 101
12.3.2. Monitoring of Climatic Conditions 101
12.3.3. Automation of Protected Spaces – Smart Greenhouses 103

13. Crop Management 104
13.1. Agricultural Unmanned Aerial Vehicles (UAV) 105

14. Sensors in Agriculture 112
14.1. Types of Soil Sensors 115
14.1.1. Mechanical Sensors 116
14.1.2. Electrochemical Sensors 118
14.1.3. Electrical and Electromagnetic Sensors 120
14.1.4. Chemical Sensors 122
14.1.5. Optical Sensors 126
14.1.6. Acoustic Sensors 127
14.1.7. Physical Sensors 127
14.1.8. Soil NPK Sensors 129
14.1.9. Portable Detectors 130
14.1.10. Vehicular Detectors 131
14.1.11. Moisture Sensor 131
14.1.12. Soil pH Sensors 133
14.1.13. Temperature Sensors 135
14.1.14. Pressure Sensors 136
14.1.15. Level Sensors 137
14.1.16. Proximity Sensors 137
14.1.17. Water Quality Sensors 137

15. LoRA and LoRaWAN, as a Way of Networking IoT in Agriculture .. 138
15.1. Implementation of LoRA and LoRaWAN Technologies 139
15.1.1. LoRA 139
15.1.2. Application of LoRa Technology in Agriculture 140
15.1.3. A Smart System for Monitoring the Environment 141
15.1.4. Energy Harvesting Device 142
15.1.5. Smart Mobile System for Agriculture 142
15.1.6. System for Sending Images Using LoRa Technology 143
15.1.7. Automatic Irrigation System 144

15.2. LoRa WAN......145
15.2.1. LoRaWAN Class......147
15.2.2. LoRa WAN Sensors with Application in Agriculture......148
15.2.3. Advantages of Security Features of LoRaWAN Technology......149
15.2.4. Disadvantages of Security Features of LoRaWAN Technology......151

16. Standard Systems of Agricultural IoT......152

Chapter II......153
Application of IoT Techniques in the Soil Nutrients Assessment

1. Introduction......153

2. Soil as a Factor for Agricultural Production......155

3. Soil Fertility and Productivity......159

4. Agrochemical Properties of the Soil......162
4.1. Agrotechnical Measures of the Soil......165
4.2. Importance of Soil Properties and Fertility......169
4.3. Importance of Agrochemical Soil Analysis......172
4.4. Collection and Preparation of Soil Samples for Laboratory Tests......175
4.5. Challenges of Traditional Soil Nutrient Analysis......179
4.6. Soil Nutrients......186
4.6.1. Forms of Nutrient Elements in Soil......189
4.6.2. Mobile Nutrients......191
4.6.3. Reserve Nutrients......193
4.6.4. Dynamics of Nutrient Elements in the Soil......193

5. Information System for Soil Nutrients Assessment......196
5.1. IoT-Based System for Soil Nutrient Assessment......199
5.2. Soil Fertility Analysis Using IoT......199
5.3. Sensing Technologies for Soil Quality Assessment......222
5.3.1. Optical Sensing Methods for Assessment of Soil Macronutrients......223
5.3.2. Visible Light-Sensing Methods......229
5.3.3. Colorimetry......231
5.3.4. Spectroscopic Methods for Sensing Soil Properties......234

5.3.5. Near-Infrared and Infrared Sensing Methods......................234
5.3.6. Attenuated Total Reflectance Spectroscopy (ATRS)..........240
5.3.7. Vis–IR Spectroscopy 240
5.3.8. Raman Spectroscopy...241
5.3.8.1. Application of Raman Spectroscopy to Qualitative and Quantitative Analysis 242
5.3.9. Fourier Transform Infrared (FTIR) Spectroscopy 245
5.3.10. Mid-Infrared Spectroscopy 249
5.3.11. Traditional Instrumental Methods of Analysis..................249
5.3.11.1. Electrochemical (Electroanalytical) Traditional Methods 251
5.3.11.2. Electrochemical Sensing Methods...........................252
5.3.12. Ion-Selective Field-Effect Transistors (ISFET)................256
5.3.12.1. Ion-Selective Electrodes (ISE) 258
5.4. Soil Heavy Metal Detection 260

6. Benefits and Pitfalls of IoT-Enabled Agricultural Systems.................262

Bibliography 267

Biography of the Authors 299

Digital agriculture is revolutionizing farming by turning data into actionable insights, optimizing everything from soil health to harvest timing.

~ Robert Saik

PREFACE

The integration of smart agricultural production, soil fertility evaluation, and innovative IoT applications plays a crucial role in advancing sustainable farming practices for future generations. These elements collectively contribute to a more efficient and sustainable agricultural system.

The monograph **IoT Techniques for Digital Agriculture Monitoring and Soil Nutrients Assessment** offers a comprehensive exploration of global research and practical experiences in implementing IoT technologies for agricultural production and soil fertility analysis. With the growing global population, there is an increasing need for food production that upholds both quality and safety standards. In this context, the book serves as a valuable guide to the digital transformation of agriculture, aligning with the principles of the fourth industrial revolution. It highlights how IoT-driven agricultural practices enhance efficiency and sustainability compared to traditional farming methods.

The first chapter provides an overview of agricultural production, highlighting its essential role in human survival and economic development. Agriculture has historically driven societal progress, fostering urbanization, workforce specialization, and technological advancements. Over time, it has evolved from primitive practices to a highly mechanized and technology-driven industry that influences global trade, environmental sustainability, and resource management.

Modern agriculture integrates numerous activities, including food production, processing, distribution, research, and environmental protection. Industrialized agriculture, characterized by mechanization, chemical inputs, and innovation, has significantly increased productivity. The sector has also benefited from technological advancements such as artificial intelligence, IoT devices, and data analytics, which optimize resource use, enhance efficiency, and improve sustainability. These innovations help farmers monitor crop health, predict yields, and manage resources like water and fertilizers more effectively.

As consumer awareness of environmental issues grows, the agricultural sector must adapt to new standards for food safety, quality control, and sustainability. The increasing demand for food, driven by population growth, necessitates the adoption of digital technologies to enhance agricultural productivity while minimizing costs and environmental impact. The application of Industry 4.0 technologies, including automation, sensors, machine learning, and AI, is transforming agricultural production by enabling precision farming, reducing waste, and ensuring better supply chain management.

Digitalization plays a crucial role in modern agriculture by integrating information and communication technologies at all production stages. This transformation leads to increased yield, improved quality control, cost reduction, and more sustainable farming practices. Key applications of digital agriculture include climate monitoring, automation in protected environments, crop management, soil condition assessment, and precision spraying.

Furthermore, digital agriculture enhances traceability, allowing consumers to access detailed information about food origins and production methods. It also helps reduce the ecological footprint of farming by optimizing input usage and minimizing waste. As the agricultural sector continues to evolve, embracing new technologies will be essential to ensure food security, environmental protection, and economic stability.

By leveraging technological advancements and digital solutions, modern agriculture is not only increasing efficiency and productivity but also shaping a more sustainable and resilient future for global food production.

The second chapter emphasizes the crucial role of soil fertility in plant development and agricultural productivity. Soil is a fundamental resource that must be managed with precision to ensure sustainable production. Its fertility determines its ability to provide plants with essential nutrients, water, air, and heat, all of which support root system development. Soil fertility is influenced by physical, chemical, and biological properties, and different soil types vary in their potential to produce high yields. From an agrochemical perspective, fertile soil consistently supplies nutrients throughout the growing season, enabling plants to achieve high productivity. The term productivity is often associated with soil fertility, as it directly impacts crop yields within specific agroecological conditions.

Fertilization is one of the most significant agronomic practices for maintaining soil fertility, contributing to approximately 50% of yield increases compared to other measures such as cultivation, irrigation, and pest control. Conducting agrochemical analysis is essential for assessing the nutrient content of the soil, monitoring changes in macro- and micronutrient levels, and determining the optimal fertilization strategy. Soil testing evaluates key indicators such as soil organic carbon, nitrogen, phosphorus, potassium, electrical conductivity, and pH levels, ensuring the right balance of nutrients for crop growth.

Traditional soil testing methods, including random, adaptive, or grid sampling, involve collecting and analyzing soil samples in laboratories or on-site. However, these approaches are time-consuming, expensive, and lack the high spatial and temporal resolution necessary for precision agriculture. The inability to capture real-time fluctuations in soil conditions limits the effectiveness of soil management strategies. To overcome these challenges, advanced technologies such as the Internet of Things (IoT) and unmanned aerial vehicles (UAVs) have transformed soil monitoring. Wireless sensors and IoT-based solutions provide continuous data on soil moisture, temperature, and nutrient levels, offering farmers real-time insights into soil health. These innovations help address key agricultural challenges, including disease management, irrigation efficiency, and climate adaptation.

Intelligent soil fertility analysis utilizes modern sensing technologies, including spectroscopy, geospatial analysis, and electrochemical sensors, to assess soil quality. Optical sensing techniques, such as reflectance spectroscopy, analyze soil composition based on light absorption, while electrochemical sensors detect specific nutrient ion activity. These technologies enhance precision agriculture by enabling farmers to make data-driven decisions that improve crop yields, maintain soil fertility, and promote sustainable farming practices. The integration of these advanced approaches marks a significant shift in soil management, ensuring efficient resource use and long-term agricultural sustainability.

IoT technology has the potential to revolutionize agriculture and food production by enhancing product quality, boosting crop yields, optimizing resource use, and enabling farmers to manage costs more efficiently.

This monograph serves as a crucial resource for understanding digitalization and leveraging IoT solutions to improve agricultural practices. It offers valuable insights, practical guidance, and extensive research, making it an essential read for those approaching digitalization from a scientific perspective, practitioners already utilizing IoT technologies, and students looking to deepen their knowledge in the field. Additionally, it provides valuable information for producers and readers seeking to expand their expertise and achieve sustainable, eco-friendly, and profitable agricultural production. By applying the principles outlined in this monograph, readers can enhance both the efficiency and output of their agricultural operations.

~ Authors

CHAPTER I

THE ROLE OF DIGITAL AGRICULTURE MONITORING SYSTEM THROUGH IOT-BASED TECHNIQUES

1. Introduction

Agricultural production increasingly relies on modern techniques to enhance productivity, sustainability, and efficiency. Modern agricultural methods have revolutionized the industry by offering innovative solutions to address various challenges and improve productivity. Nanotechnology, for example, has shown promising applications in precision agriculture, aiding in crop protection and enhancing plant growth. Additionally, the integration of modern technologies such as deep learning and the Internet of Things has led to the development of intelligent agriculture, promoting efficient resource utilization and overall agricultural development (Sun et al., 2022).

Agriculture is the backbone of a country's economy, providing essential ingredients as well as industrial raw materials. Despite the continued growth of agriculture in the country, the inadequate availability of agrarian inputs limits output. Technological advancements have significantly transformed agriculture, largely due to the integration of various devices and systems to automate tasks (Rashid and Salim, 2022).

Furthermore, the use of modern agricultural techniques, including precision agriculture management systems and unmanned aerial vehicles, has proven effective in enhancing sustainability and productivity on small farms (Loures et al., 2020). Additionally, selectively integrating modern agricultural techniques with traditional agroecological systems has been shown to improve soil fertility and agricultural productivity, highlighting the potential for sustainable agricultural development (Faye, 2020).

Modern agricultural techniques hold the potential to address various challenges, improve productivity, and contribute to the overall sustainability and development of the agricultural sector. By leveraging advancements in technology and innovative approaches, modern agriculture is poised to meet the demands of a rapidly evolving global landscape while ensuring sustainable and efficient practices.

Precision agriculture, also known as precision farming, is a modern approach to agricultural management that utilizes advanced technologies to optimize production efficiency, enhance crop quality, and minimize environmental impact. This approach integrates various precision agriculture techniques, such as remote sensing, GPS, and drones, enabling data-driven decision-making and targeted resource management (Shehzadi et al., 2023).

Internet of Things (IoT) technology is set to revolutionize the world of information, following in the footsteps of computers, the internet, and mobile communication networks. It breaks traditional boundaries and opens new technical fields. IoT technology encompasses three dimensions: information items, independent networks, and intelligent applications. It integrates heterogeneous smart devices and interoperable communication technologies, such as RFID, WSN, sensors, and GPS actuator networks, which enable identification, tracking, communication, monitoring, and interaction with physical objects. By providing a flexible control mechanism for real-time data acquisition from the field, IoT technology has become a promising solution for various agricultural applications. IoT-based agricultural applications include irrigation, precision farming, greenhouses, cold chain control, machine and process control based on M2M, environmental monitoring, traceability, and quality monitoring (Ping et al., 2018).

IoT technology enables efficient remote crop monitoring by providing real-time information on climate, humidity, temperature, and soil fertility, among other factors. This allows farmers to monitor the state of their crops at any time and from any location (Verma et al., 2022).

2. Importance of Agricultural Production

Agriculture is one of the oldest, but also the most important branches of the economy that provides food – a key resource for survival. Agriculture arose out of the human need for food and basic resources for survival. Without agriculture, it would not be possible to satisfy these basic life needs.

Agriculture became the fundamental activity that shaped human culture, the organization of society, and the way of life. Understanding the history of agriculture provides insight into the economic changes and laws that have shaped the development of societies throughout the ages. Agriculture played a key role in the development of societies, enabling urbanization and the specialization of the workforce. Advances in agriculture have fueled the development of technology, from primitive tools to modern farm machinery and genetically modified crops. Agriculture is a global activity that affects world economic relations, trade, the environment, and resources.

Unlike other production activities, agriculture is specific in that its success depends on and is exclusively connected to the natural environment in which all agricultural processes take place. These features and peculiarities derive from its attachment to the natural environment (dependency on that environment) and from the fact that it essentially rests on a series of biological and biochemical processes of conversion of inorganic matter into organic matter (Defilippis, 2002).

The broadest definition of agriculture includes the cultivation of plants and animals for the production of food, raw materials for industry, energy, and many other products. In addition, modern agriculture includes many other activities such as processing, distribution, trade, research and development, technological progress, and environmental protection. Likewise, the emphasis on the industrial mode of production in agriculture indicates the transformation of agriculture over time, where mechanization, the use of chemicals, and technological innovation play a significant role in increasing productivity and enabling greater production.

Likewise, the world is changing day by day – accelerated urbanization, climate change, and changes in consumer habits are just some of the challenges facing agriculture today. Agriculture as an activity has many branches. Ever since the beginning of humans, people have been engaged in agricultural activity in the form of planting certain plants and taking their products. As information and communication technology began to develop more and more, it also began to enter the spheres of agricultural activities.

Although it depends above all on natural conditions, such as climate, geographical location, quality, and other characteristics of the land, agriculture is an economic activity whose carrier is man, so its development is impossible to observe independently of the general development of human society, i.e. the development of human consciousness as the key bearer of the development process. Thus, four characteristic periods can be distinguished in the development of agriculture:

1. Period of agricultural civilization or agricultural revolution;
2. Period of the industrial revolution or industrialism;
3. Post-Dnustarian era – information society;
4. Period of welfare-based development.

In each of the mentioned four periods, there are differences related to the key factors of development, as well as the place and importance of agriculture in the overall economic development (Djuric, 2015). As an economic activity, agriculture is characterized by numerous specificities. Land, as an objective condition of agricultural production, largely determines the production and economic effects that are realized in this economic activity. With its characteristics, land primarily affects the possibility of organizing agricultural production in a certain location. Also, the specifics of the land determine the arrangement and organization of the economic yard, the level of production intensity, the management method, the amount of yield, and the investment per unit area. The specifics of agriculture can be divided into three groups. They are:

1. Specifics related to the land;
2. Specifics of the production process in agriculture;
3. Specifics of the agricultural enterprise.

The specificities of the land are marked by its properties such as permanence, i.e., inexhaustibility, immobility, non-reproducibility, and different fertility. The specifics of the production process in agriculture are reflected, first of all, in the pronounced influence of climatic and geographical conditions on the production process and its result. Then, in contrast to industry or some other economic activity, in agriculture, the biological character of the subject of work, i.e., the basic material, is present. The discrepancy between the time of investment in the production of human labor and the production process determines another specificity of agricultural production, which is its pronounced seasonal character. The existence of production for one's reproduction is another of the specificities that determine the production process in agriculture. The specificity of the agricultural enterprise in terms of organization and management methods derives from the aforementioned specificities of the production process and land as a basic resource in this economic activity. All the specifics of an agricultural enterprise can be sublimated in the search for answers to the questions of what, how, how much, and for whom to produce (Djuric, 2015).

Advances in agriculture have fueled the development of technology, from primitive tools to modern farm machinery and genetically modified crops. Agriculture is a global activity that affects world economic relations, trade, the environment, and resources. In today's world, agriculture faces challenges such as sustainability, climate change, and increased demand for food. Its role remains crucial for the future of humanity (Djuric, 2015).

2.1. The Vision of Agricultural Development

The vision of agricultural development is usually based on long-term goals and desired changes in the agricultural sector. The vision is often expressed as the desire for a sustainable, productive, and equitable agricultural system that meets the needs of current and future generations. The key elements that form part of the vision of agricultural development are (Defilippis, 2002):

1. **Sustainability:** The vision of agricultural development usually includes sustainability as a basic principle. Sustainable agriculture promotes the economic, environmental, and social aspects of agricultural production to ensure that resources such as soil, water, and biological diversity are preserved for future generations;
2. **Increasing productivity:** The vision often includes the goal of increasing agricultural productivity to ensure sufficient food, raw materials, and other agricultural products for a growing world population;
3. **Reduction of poverty and inequality:** Agricultural development often includes the goal of reducing poverty among the rural population and reducing inequality in access to resources and rights;
4. **Diversification of production:** The vision of agricultural development may include diversification of production to increase the stability of agricultural holdings and rural communities through the diversity of crops and services;
5. **Innovations and technologies:** The vision usually recognizes the importance of innovations and technological advances in agriculture to improve productivity, reduce losses, and increase sustainability;
6. **Proper management of natural resources:** Conservation and proper management of natural resources such as soil, water, and forests are often key elements of the vision of agricultural development;
7. **Food quality and safety:** The vision includes the goal of ensuring food quality and food safety for the population;

8. **Economic development of rural areas:** Agriculture plays a key role in the economic development of rural areas, so the vision includes the goal of improving living conditions and infrastructure in these areas;
9. **Cultural heritage:** Preservation of cultural heritage and traditions in agriculture can also be part of the development vision.

Current agriculture will not be able to respond to all these challenges, as well as to the greater need for food production. That is why changes in business approaches, a higher level of innovation, and the technological transformation of agriculture are necessary. It is interesting that agriculture, as one of the fundamental branches of humanity, ranks last in terms of the degree of digitization and application of digital solutions.

The use of technology within agricultural activities aims to make it easier for people to work on farms or agricultural land. Since agriculture is one of the activities that depends on many factors, whether it is genetics in animals, seed grains, or fertilizers and pesticides for plant protection, it mostly depends on weather conditions. For humans to be able to influence the listed factors in addition to weather conditions, certain technologies are used to extract the maximum possible profit from each activity at that moment.

Agriculture is one of the major sectors that contribute to the growth of the country’s economy and it provides numerous employment opportunities to people in developing countries. Agriculture is an essential human activity, highly dependent on meteorological conditions, and the focus of research and innovation to afront several challenges. Climate change, global warming, and the degradation of agricultural ecosystems are just a few of the problems that humans are facing in continuing essential food production.

The basic goals of managing agricultural resources at a specific location are to increase the profitability of plant production, improve product quality, and protect the environment. Information about the variability of different soil properties within a field is essential for the decision-making process. The inability to obtain soil characteristics quickly and cheaply remains one of the biggest limitations of precision agriculture. With the help of smart sensor technology and the development of the Internet of Things (IoT), farmers today have greater options in terms of monitoring crops, monitoring the condition of agricultural areas, and general work on the farm. With the increase in the human population, the need for food and other agricultural products is increasing, which especially requires the rational use of agricultural land, its protection from inappropriate use, as well as protection from natural erosion and general devastation. There is often a need to assess and determine the distribution and possible productivity of land, especially in hilly and mountainous areas. It is also sometimes necessary to carry out planning for the cultivation of non-cultivable areas (wasteland) and thus expand the total fund of agricultural land. In addition, it is often necessary to carry out land melioration and thereby increase their productivity. There is also often a need to monitor crops, their development, and yield assessment. For the aforementioned and other studies of land and agricultural crops, remote sensing methods can be successfully used, as well as sensors that make up a collective intelligence with which information can be obtained quickly, cheaply, and reliably.

It is this information that indicates that agriculture needs to be changed, and modernized, and introduces technologies that increase productivity. The implementation of digital technologies, data analytics, and IoT (Internet of Things) offers the potential to transform the strategy of farmers and their businesses, which ultimately leads to increased productivity and sustainability in the agricultural sector. Such agriculture will be able to respond to the challenges it faces and to the needs of humanity.

Agriculture is one of the oldest trades in the world. With the constant advancement of technology and the release of new services, this branch of industry also takes on constant growth and development in the technological aspect. Every economy has a computer or some other electronic device that supports development. Nowadays, there is no new machine that does not have a system of electronically assisted functions (from self-driving tractors to smart grain sprayers that load sensors with weeds and control them selectively).

Agriculture is an integral part of the human community. It has been upgraded with time to increase agricultural yields. Modern technologies have also been employed in agriculture, horticulture, and forestry for better monitoring of plant growth, diseases, and pest populations. AI and IoT have numerous burgeoning scopes in agriculture to solve various issues like soil conditions, weather status, pest detection, determination of harvesting time, and so on (Kaloxylos et al., 2023).

3. Digitalization in Agriculture

The agricultural sector plays a significant role in the development of the whole economy of any country. The rapid global increase in population makes food and crop production important. So, a lot of technological changes have been observed in this sector. There are many ways that crop production and its storage are carried out. The IoT, smart technologies, artificial intelligence, and automated devices are available in smart farming. Sometimes, implementing these technologies requires expertise and is also costly. Precision agriculture is a significant part of agriculture, in which data transmission technology is also vital (Senapaty et al., 2023).

The agriculture industry plays an essential role in the world economy. A thousand years ago, people started working on farms, and now it has tremendously increased and contributed a lot to global trends. Population growth, protection from the environment, climate change, and rich quality and quantity of food require the latest tools. This has given a new dimension to researchers, engineers, scientists, and business holders in the area of agriculture (Katiyar and Farhana, 2021).

Agricultural IoT technology connects field machines to computing devices for seamlessly supporting more effective data-driven farming through integrating sensing, data processing, decision-making, and automated control technologies in an IoT platform (Villa-Henriksen et al., 2020). Data communication, either wired or wireless, provides the base for networking all interrelated devices seamlessly in operating. The “data” here is a general term and could be either analog signals outputted from some analog sensors, digital signals communicating between computing devices, imaging signals from camera or imaging sensors, or voice signals from recorders, phones, or even TVs, depending on the type of devices being connected in an IoT.

Smart agriculture is defined as an agricultural system in which the most advanced technologies are integrated with traditional approaches to agriculture to improve the quality and quantity of agricultural production, while at the same time significantly reducing inputs, improving productivity, yield, and profit, and reducing the impact on the environment (Roser et al., 2019).

Digitization has a great impact on agriculture, with one hundred key questions that need to be answered:

- How to improve existing business processes and models?
- How to create a new innovative business model?
- How to increase existing and create new value?

Some of the application domains of digitization in agriculture are:

- agricultural crops;
- fruits and vegetables;
- animal husbandry;
- supply chain.

Agriculture has undergone a great transformation during the last few decades, shifting production from small/medium farmers to highly specialized and commercial farming operations. With the rise of Industry 4.0, the development of wireless communication, cloud computing, machine learning, and Big Data technologies, Internet of Things technology is gradually being applied in a wide range of agricultural uses. The emerging agri-tech revolution aims to use advanced precision technology, such as real-time soil nutrient sensors and the Internet of Things (IoT), to meet the future demands for food, fiber, and fuel in a more sustainable, efficient, and eco-friendly manner. Advanced information technologies allow faster and more stable transmission of sensor data and are becoming more affordable due to the miniaturization of hardware and lower material costs. The implementation of IoT in agriculture can help create an informed, connected, developed, and adaptable rural community. Low-cost embedded devices can improve the interaction between humans and the physical world. Given that soil productivity has spatial and temporal variability influenced by intrinsic (parent material, climate, topography) and extrinsic (farm management practices) factors, a site-specific management system that continuously collects and processes soil information data can efficiently optimize farm inputs through data-driven decision-making. Precision agriculture is a data-demanding system that incorporates intelligent sensing systems, cloud computing, and edge computing into a single platform (Lvova and Nadporozhskaya, 2017).

Since agriculture is an important sector in the economy of every country, the traditional methods that have been used for decades to produce food today cannot meet the significantly increased needs. The goal of applying new technologies in agriculture is to increase yield, reduce harvest time, reduce costs, and impact the environment. The new era implies the use of technologies, applications, and solutions implemented in the Industry 4.0 concept, which radically transforms the production possibilities of all industries, including agriculture (Bonneau and Copigneaux, 2017). The integration of new technologies with modern agriculture results in better production and easier management of the supply chain (Radić et al., 2022).

The agricultural industry has transformed significantly in the last 40-50 years. In the period from 1970 to 2023, we are getting closer to full automation day by day. Advances in machinery expanded the ratio, speed, and productivity of overall agricultural equipment, leading to more efficient crop cultivation. Seeds, irrigation, and mineral resources have also been significantly improved by the use of modern agricultural techniques and timely testing in laboratories and comparison with previous yields, taking into account the least possible losses and better product quality (a large amount of product with a very small proportion of toxicity due to various chemical agents or mechanical problems), helping farmers to increase yields at the same time. Now, agriculture is in the early days of another great advance, aided by innovative technologies. Modern agriculture offers us artificial intelligence, analytical processes, connected sensors, and other new technologies that could further increase yields, improve the efficiency of water and other inputs, and build sustainability and resilience in crop production and livestock. The future of agriculture cannot be achieved without digital tools and a strong push for technological innovation. With increasing consumer awareness of environmental issues and the need for better management of available resources, new concepts of healthiness, quality, and control have been greatly improved.

The third industrial revolution, better known as Industry 3.0, brings technological progress that transforms precision agriculture into digital, which, compared to precision, puts a greater focus on technology (Karunathilake et al., 2023). Smart agriculture is based on data-data collection, processing, analytics, and decision-making based on information. Conventional agriculture did not take any of this into account. One example of the benefits of digitization in agriculture is precision seeding, which studies show is 10 to 30% more efficient than conventional seeding (Karunathilake et al., 2023).

In 2011, the fourth industrial revolution took place, known as Industry 4.0, which introduced the Internet of Things (IoT), artificial intelligence, robotics, and blockchain technology. These novelties have been implemented in agriculture in one way, changing digital agriculture to smart agriculture or agriculture 4.0 (Karunathilake et al., 2023).

With the emergence of Agriculture 4.0 as the center of innovative technology, modern agriculture has revolutionized agriculture as an economic activity, it encompasses the development of precision agriculture and refers to all actions carried out in agriculture based on the precise and accurate analysis of data and information collected and transmitted through advanced technology and available tools. These are tools and strategies that enable the simultaneous use of many digital 4.0 technologies, in turn enabling the automatic collection integration and analysis of data collected from the field, whether from sensors or other sources. Smart agriculture, i.e., agriculture 4.0, limits human involvement to observation, monitoring, and management of agricultural processes, while collection, processing, and decision-making are automated and done technologically (Karunathilake et al., 2023).

The task of these technologies is to offer the most extensive and precise support to farmers in the decision-making process related to their activity and relationship with other parties in the spraying chain. This improves economic, ecological, and social sustainability, as well as the profitability of agricultural processes.

Agriculture, which is an essential part of every community, also belongs to the digital transformation. Digital transformation also leads to technological progress from several perspectives. Agriculture 4.0 is supported by innovative technology. It has digitized agricultural applications, machines, and remotely controlled tools supported by artificial intelligence. The foundations of all innovations are Bluetooth and the Internet. The equipment has sensors that collect data. Farmers or people from other industries can access information, be it about fields, vehicles, or crops. The reach of this accessible information is several kilometers. The equipment can also be controlled remotely. There is a possibility that an automated device will solve the problem by itself in the future without any human help (Agrowell, 2021).

Further development of new tools and machines will certainly ensure high efficiency, quality, and then environmental protection. The primary tools for development in the agricultural industry are tractors, so their maintenance and quality are essential. Using connectivity and location technology optimizes the use of agricultural vehicles. With this technology, sowing and harvesting time can be significantly reduced; also, the introduction of this technology will certainly reduce fuel consumption (Agrowell, 2021). Agriculture 4.0 aims to achieve the following tasks:

- provide food and increase its quality;
- adjustment in the event of numerous difficulties at work;
- reduce the emission of greenhouse gases.

The ultimate goal of Agriculture 4.0 is to increase economic, ecological, and social sustainability–as well as the profitability of agricultural processes. Agriculture 4.0 refers to the use of large amounts of data, artificial intelligence, and robotics to expand, accelerate, and increase the efficiency of activities that affect the entire production chain (Agrowell, 2021).

Adoption of 4.0 solutions in agriculture and data management to properly use 4.0 solutions in agriculture. The following procedures are necessary:

- avoidance of unnecessary waste by calculating the exact needs for irrigation of crops or detecting in advance the occurrence of certain plant diseases or pests;
- greater control over costs and the ability to plan all stages of cultivation, sowing, and harvesting with great precision, saving both time and money;
- supply chain improvement can result in a short supply chain capable of producing high-quality food sustainably with little room for error.

When talking about data management in agriculture 4.0, it is understood:

1. Use of innovative technologies;
2. Ability to manage the amount of data and information coming from the field;
3. Ability to interpret them in a useful way for the sector (Mccormick, 2021).

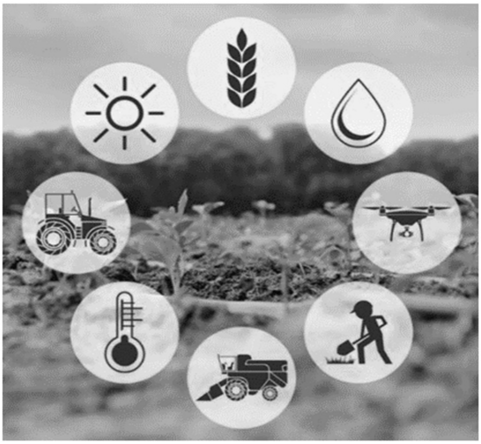

Fig. 1-1. A smart agriculture network consisting of crops, required irrigation, drones, labor, tractors, temperature regime, daylighting, and more (source: https://www.gruber-genetti.it/en/blog/b/smart-farming-agriculture-4-0-part-i_22).

Agriculture faces many challenges such as food security, climate change, water scarcity, and environmental degradation in the years to come, thus making preservation and sustainable management of soils a crucial priority in tackling these challenges (Figure 1-1). The rising utilization of food crops for various industries (bioenergy, biofuel) is further increasing the pressure on a scarce agricultural resource as well as posing a serious threat to the availability of arable land. The preceding solar minimum brings about many changes in the atmosphere that will lead to dramatic shifts in weather conditions globally. However, recent technical advances in electronics, digital signal processing, and miniaturization of sensing hardware provide an opportunity to tackle many future challenges.

In the process of designing and developing a digital agriculture system, it is important to follow the following methodological steps (Stojanovic, 2021):

1. Analyze the need for an e-agriculture system for a dedicated application. SWOT analysis can be used as a tool to indicate strengths, weaknesses, opportunities, and threats related to business competition or project planning;
2. Defining goals and purposes. Each production has priorities. If production is in a dryland area, soil moisture monitoring may be the primary objective at that location. The key goals to be achieved will ultimately determine the rest of the project – from the sensor structure to the software architecture. It is preferable to start with one priority;
3. Decide on data transmission technology. Transfer automatically or manually, raw data or sparse data, near or far, inside or outside. What technology to use for data transfer, from serial to WPLAN from wired to wireless network;
4. Determine power sources. The data transmission distance is also important as it directly affects the battery life of the sensor. Energy consumption can be managed by regulating the frequency of data transfer or by transferring a smaller amount of data. One way or another. Energy consumption and energy sources will require preliminary estimates;
5. To estimate the frequency of data collection. The power consumption and lifetime of the sensor will also depend on the frequency of data collection. How often should the necessary data be collected to achieve value;
6. To study the specification of the sensor. Select the appropriate sensor. The selection of sensors is a very professional job, from the range to the housing. Take into account that most measurements are “physiological”;

7. Consider self-calibration. Usually, the design skips this point, but how will you know your sensor is sending the correct value? As an example is measuring pH.
8. Make a mini model and test the system. Usually, in the laboratory or “mini garden”, you need to make a mini test system. The system should work on models;
9. Install the system on-site. It is a demanding job, not only electronics or ICT, you need mechanical engineering, construction, craftsmen;
10. On-site trial work. To carry out examination procedures (Stojanovic, 2021).

Digitization of farming processes and activities is an important challenge for the adoption of smart agriculture technologies (Farooq et al., 2019; Sinha and Dhanalakshmi, 2022).

In particular, the major challenges to digitization in agriculture can be categorized as follows:

1. **Communication Issues:** Large-scale implementations of IoT solutions require robust and secure network architectures. The reliability of communicating information still represents a challenge to be addressed in the agricultural context and justifies the adoption of LoRa/LoRaWAN technologies;
2. **Energy Management:** The power supply in devices for smart agriculture is a significant challenge, and energy harvesting systems are a relevant area of research. The main issue concerns the sensor’s power supply and how to optimize efficiently the power consumption. Moreover, distributed nodes can execute some computations (Edge Computing), which consume more energy, while sensor batteries have a limited capacity. Consequently, smart devices require efficient energy storage and supply;
3. **Data/Device Heterogeneity:** In general, agricultural data is produced by heterogeneous sensors (soil sensors, weather sensors, trunk sensors, leaf sensors, etc.). In addition, IoT devices generally use different network protocols and platforms. Thus, in addition to sensor heterogeneity, network and protocol heterogeneity should be considered as well. Getting these technologies to work together is often an issue, especially for unskilled farmers;
4. **Physical Deployments:** Spatial deployment of devices on farms proves to be a significant challenge, especially when the entire farm needs to be monitored across a large area and with different application scenarios (soil, plants, trees, animals, etc.);

5. **Data Management:** The difficulty of interpreting the data can be a huge barrier: indeed, numerous sensors are necessary, and big data analysis could be required to better understand and forecast the unpredictability of agricultural ecosystems;
6. **Generic Platform:** To promote the adoption of smart agriculture technologies, it is often required to develop user-friendly software platforms. The challenge here is to build a universal platform that can be easily modified to support different types of monitoring, ranging from specific crops to livestock.

These challenges, together with the cost of infrastructure investment, the complexity of technologies, the lack of farmers' education and training, data ownership, and privacy and security concerns, have motivated the research and development of innovative platforms, specific network technologies, and new architectures for smart agriculture (Pagano et al., 2023).

3.1. Innovative Technologies in Agriculture that are Used to Digitize the Agricultural Enterprise

Digital service technologies consist of various tools, platforms, and systems used to deliver services to customers. All of the above include a wide range of technologies, such as cloud computing, artificial intelligence, the Internet of Things, big data, virtual and augmented reality, mobile technologies, and many others. These technologies play a key role in enabling companies to create and deliver digital services that can attract a multitude of users. They provide them with process automation, information gathering, and increased efficiency of the company's work. As technologies advance, services evolve and provide an opportunity for companies to give customers innovative ways to work easier and better (IBM, 2020). Digital services represent a new way of doing business in which digital technologies are used to provide services to customers. Today, they are crucial in every business sector, including the agricultural sector. Digital services in agriculture include various technologies used to collect, analyze, and interpret data on agricultural crops, soil, water, weather conditions, and other factors that affect agricultural production.

3.1.1. Cloud Computing (Fog Computing)

IoT can take advantage of the benefits of the cloud features and resources to overcome its limitations, such as storage, processing, and communication. Using cloud and IoT together will facilitate the implementation of a high-speed information system between the surveillance entity and the sensors/actuators deployed in the area. IoT along with cloud computing has become a technology of the future, and its applications have been used in many sectors, including agriculture (Friha et al., 2021).

Fog computing or fog networking, as used interchangeably, is a computer infrastructure decentralized using computational resources to perform extensive functions between source data and the cloud. With this concept, workstations are made to process information from IoT terminals in real-time. The concepts of fog computing arose from the need to extend cloud computing. It has local communication endpoints and data gathered can be routed to the internet. Today, in agriculture, the use of fog computing cannot be avoided since IoT is becoming more popular, real-time data and information are required to be explored in real-time and accessed remotely. Fog networking is crucial for the efficient deployment of IoT applications in smart farming processes in the crop farming industry. It is a backbone for real-time automation with numerous advantages including privacy, security, bandwidth, latency, productivity, etc., fog computing has found its applications not only in agriculture but also in smart cities, video surveillance, smart homes, and healthcare to mention a few. On the other hand, cloud computing is the act of accessing and keeping data, programs, and information on a large computing infrastructure that is hosted online instead of having it locally on a physical server within the office or a personal computer. Cloud computing is popularly referred to as Internet computing. In agriculture, cloud computing concepts have been used at the base level in product dissemination, report writing, seeds, progress reports drafting, project management, etc. Files involved in the aforementioned activities are stored on cloud services. Cloud computing involves front and back end, communication, and Internet management. It involves three major layers infrastructure as a service, platform as a service, and application as a service. Agriculture and crop farming are not exempt from the challenges of processing vast amounts of data. In the context of the ongoing industrial revolution, this research aims to leverage IoT and related components to address these issues (Ndjuluwa et al., 2023).

Cloud computing is a model of providing computing resources over the Internet. This technology provides the availability of resources on demand of the computing system, such as data storage, processing power, operational memory, and connectivity. This technology relies, similarly to IoT, on the availability of high-speed Internet (throughput) and allows users to use resources without direct participation in management. This model