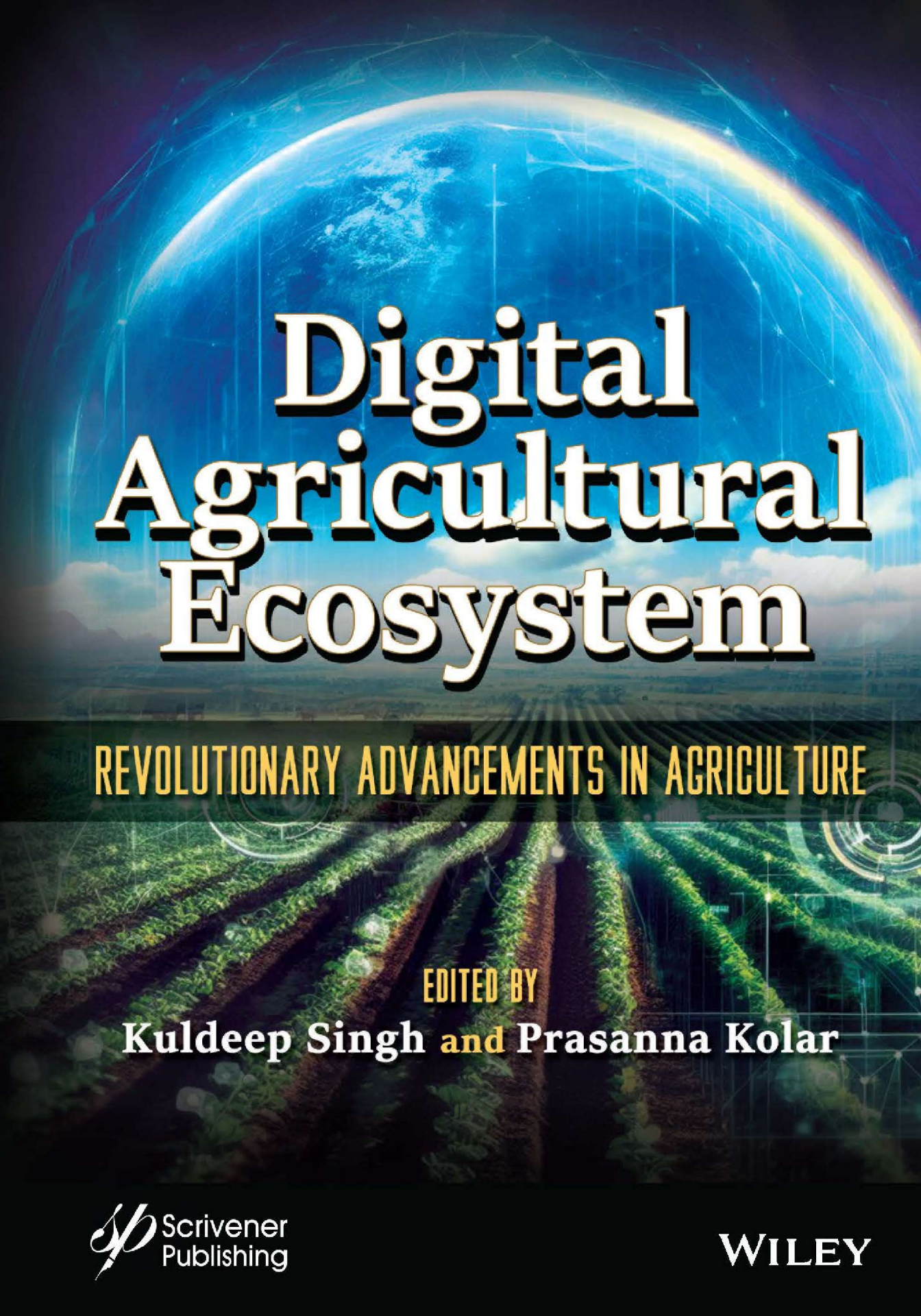
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EDITED BY
Kuldeep Singh and Prasanna Kolar
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Revolutionary Advancements in Agriculture

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Dedication

We humbly dedicate this edited book, 'Digital Agricultural Ecosystem,' to the cherished memories of those whose invaluable influence and unwavering support have shaped our lives and inspired the pursuit of knowledge in the field of agriculture. We pay homage to *Shri Harishchandra Master Ji*, the grandfather of Dr. Kuldeep Singh, whose profound wisdom as a science teacher in Jhunjhunu, Rajasthan, continues to resonate in our hearts. After his honorable retirement, he imparted invaluable insights about agriculture, its challenges, and its significance at the grassroots level. In loving memory of *Late Fauji Ravinder Singh*, the father of Dr. Kuldeep Singh, who devoted his entire career to serving in the Indian Army. His dedication, discipline, and selflessness have been a guiding light, inspiring us to strive for excellence in our endeavors. With boundless love and gratitude, we acknowledge *Mrs. Suresh Devi*, the mother of Dr. Kuldeep Singh, whose genuine affection for the soil and profound knowledge of agricultural practices has been a wellspring of motivation. Her insights into the realities of rural agriculture in Northern India have been a driving force behind our efforts. To the parents of Dr. Prasanna Kolar, *Mr. Ashok Kolar, and Mother Shakuntala Kolar*, we extend our heartfelt appreciation. Their unyielding support and encouragement have nurtured the seeds of curiosity and dedication, enabling us to explore the depths of Agricultural Economics. In remembrance of those who have come before us and in appreciation of those who walk alongside us, this book stands as a testament to the enduring legacy of knowledge and the collective pursuit of a sustainable and thriving agricultural ecosystem.

With utmost gratitude and reverence,
Dr. Kuldeep Singh and Dr. Prasanna Kolar
January 2024

Contents

Preface

Agriculture has historically been the foundation of human civilization. Its provision of sustenance and resources benefits communities all around the world. Agriculture has been practiced from the dawn of time, when our ancestors worked the land and had a close relationship with nature. Agriculture has a creative, adaptable, and innovative history, and as the digital age draws closer, agriculture is once again poised for change.

This book demonstrates the combined efforts of all the authors and co-authors involved, and will stand as a vital resource for academics and professionals who work in the sectors of agricultural and digital technologies.

The twenty chapters herein explore the connection between agricultural and technological advancements, which suggests a diversified environment. Each chapter delves into diverse tracks on four key areas.

Part 1 covers knowledge sharing in the digital agricultural ecosystem. In the context of modern agriculture, the materials here underline the importance of information flow. Through comprehensive reviews of literature and assessments of farmer participation on social media platforms, these chapters illustrate the value of information sharing for sustainable agriculture.

Part 2 explores the adoption and impact of digital technologies in agriculture. The use of cutting-edge digital technologies in agriculture is examined thoroughly in this section. The chapters included here outline how precision, artificial intelligence, and blockchain technology have the potential to transform methods of agriculture and improve food systems.

Part 3 addresses smart farming and sustainable agriculture. This section focuses on sustainability and offers details on eco-friendly production methods, the significance of smart farming in many nations, including India and the UK, and cost-effective fertilizer sprayer technologies.

Part 4 examines modelling and analysis of Agricultural systems. The last section explores how mathematical modelling and data analytics are used in agricultural systems, with insights on everything from the study of credit access constraints in rural regions to water resource management in irrigation systems.

The editors have greatly valued the contributions of each author. The information collected in this volume is largely inspired by their academic work and research experience. We would also like to express our gratitude to the co-authors whose dedication and hard work have enriched this publication. Finally, we have greatly appreciated the dedicated support and valuable assistance rendered by Martin Scrivener and the Scrivener Publishing team during the publication of this book.

Dr. Kuldeep Singh
Dr. Prasanna Kolar
January 2024

Part 1

KNOWLEDGE SHARING IN THE DIGITAL AGRICULTURAL ECOSYSTEM

1

Digital Agricultural Ecosystem: An Introduction

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Abstract
The primary goal of this chapter is to offer a comprehensive examination of digital agriculture from a critical perspective with a specific emphasis on forming an ecosystem that highlights the linkages between agriculture and technology. This chapter examines various definitions of digital agriculture and explores the theoretical foundation that supports this concept and emphasizes the essential elements required for establishing this ecosystem. The present chapter also discusses how technology has affected the development of agriculture, with a focus on the potential benefits of digital agriculture for productivity, sustainability, and profitability. Such an objective should be a top priority for government stakeholders and decision-makers due to the possible policy consequences. The research also emphasizes the necessity for the adoption of clear ethical and regulatory rules in order to secure the long-term viability of digital technologies in agriculture for the benefit of all stakeholders.

***Keywords*:** Digital, agriculture, ecosystem, sustainability

1.1 Introduction

The agriculture sector is an important pillar of the global economy and also contributes significantly to food security, economic growth, and the livelihoods of millions of people around the world. On one side, traditional agricultural methods face several challenges, such as rising costs, lower profitability, and higher demand for sustainable and environmentally friendly agro-practices. On the other side, digital agriculture has emerged as a capable solution to the abovementioned challenges with the potential to transform agro-industry through the integration of modern technology such as blockchain, artificial intelligence, big data, and the Internet of Things (IoT).

One of the most widely used definitions of digital agriculture is based on the integration of technology and data into farm practices to increase efficiency, sustainability, and profitability [1–3]. Basically, this definition encompasses various technologies such as precision agriculture, remote sensing, and decision support systems. However, this definition is still

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open to interpretation and lacks specificity in terms of the types of technologies and practices that fall under the digital agriculture umbrella.

If we look at the recent research on digital agriculture, success depends on several factors like access to technology, adoption of innovative tools by farmers, and the ability to integrate digital tools into existing agricultural systems. Despite the growing interest and investment in digital agriculture, there are several issues and controversies surrounding its use. One of the primary concerns is the digital divide where farmers in low-income countries may lack access to the necessary technology and infrastructure. Additionally, there are other concerns such as data privacy, the potential for technology to exacerbate existing inequalities, and the need for clear regulations and standards to ensure the ethical use of digital tools in agriculture.

Xie *et al.* [4] mentioned in their study that the role of technology in rural agricultural development is critical. Digital agriculture has the potential to transform farm practices and improve the livelihoods of farmers through increased yields, cost reduction, and better market access. While it is pertinent to recognize the unequal distribution of benefits in digital agriculture, there is a potential risk of exacerbating the existing digital divide due to insufficient emphasis on prioritizing technology access, particularly in low-income countries.

This article aims to provide a critical review of the available literature on the digital agriculture ecosystem with a focus on defining the relationship between agriculture and technology. The study further aims to investigate diverse interpretations and past advancements in digital agriculture. Moreover, it intends to scrutinize the fundamental components and constituents that constitute a digital agriculture ecosystem.

1.2 Digital Agricultural Ecosystem

The history of digital agriculture can be traced back to the 1970s when the first computerized decision support systems were developed to optimize agricultural practices [5]. Since then, digital agriculture has evolved significantly mainly with the integration of various technologies and the emergence of new business models and practices [6].

Upon examining the latest technological advancements in agriculture, it is evident that the digital agriculture ecosystem is a multifaceted framework that encompasses a multitude of technological constituents and participants who collaborate with each other to enhance agricultural processes. Such digital agriculture ecosystem encompasses the capacity to utilize technology and data to augment the effectiveness, sustainability, and profitability of agricultural operations. However, there is still a lack of clarity around what digital agriculture entails and how it should be defined. Therefore, by taking into consideration most of the entities and elements, we construct an ecosystem that enables us to better understand the association between technology and agriculture.

Based on the available literature on digital agriculture, it is evident that the digital agricultural ecosystem comprises a variety of entities and elements that interact with each other to optimize agricultural practices (see Figure 1.1). The entities section includes *farmers*, *technology providers*, *researchers*, *policymakers*, and *customers*. The technology providers mainly include firms that provide hardware, software, and data services for agriculture,

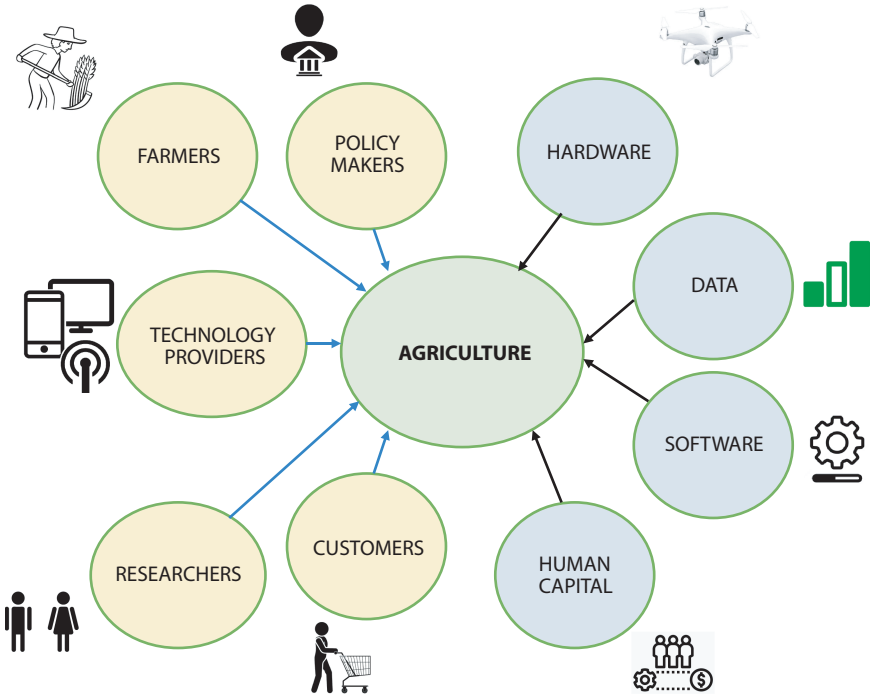

Figure 1.1 Digital agricultural ecosystem (source: authors' own).

while researchers develop new technologies and practices to improve agricultural practices. The regulatory framework that governs the adoption and implementation of digital technologies in agriculture is significantly impacted by policymakers, while customers influence the demand for sustainably produced food.

On the other side, the different elements that form the digital agricultural ecosystem include *hardware*, *software*, *data*, and *human capital*. Hardware includes sensors, drones, and other devices that collect data from the field. Software includes tools for data analysis, modeling, and visualization. Data include various types of information such as weather data, soil data, and market data. Human capital includes the skills and knowledge required to develop, deploy, and use digital agriculture technologies effectively.

The complete network of the digital agriculture ecosystem functions as a collaborative network of interdependent entities and constituents working toward shared objectives (see Figure 1.1). These objectives include improvement in the efficiency, sustainability, and profitability of farm practices; reduced environmental impact; and enhanced food security. The digital agriculture ecosystem can propose novel business prospects and value chains that are advantageous to farmers, technology providers, and consumers.

1.3 Definition

According to a FAO report [7], "digital technologies have the potential to enhance agricultural productivity and sustainability, particularly in developing countries. It highlights the

role of mobile phones, drones, satellite imagery, and other digital tools in improving access to information, markets, and financial services for smallholder farmers. It also emphasizes the need to address challenges related to digital literacy, infrastructure, and policy frameworks to ensure equitable and inclusive adoption of digital agriculture." However, the digitalization of agriculture also faces challenges such as cybersecurity, data protection, labor replacement, and digital divide. Despite these challenges, FAO is committed to bridge multidisciplinary digital divides to ensure that everyone benefits from the emergent digital society. According to the United Nations Global Compact, "digital agriculture is the use of advanced technologies integrated into a system to improve food production for farmers and stakeholders [8]. Unlike traditional methods, digital agriculture systems gather data frequently and accurately, often with external sources such as weather information [8]." As per this statement, digital agriculture integrates new and advanced technologies to enable farmers to make informed decisions based on frequent and accurate data leading to improved food production through the use of robotics and advanced machinery.

Mark Shepherd [9] mentioned how digital agriculture can offer social advantages that satisfy the needs and requirements of different stakeholders such as farmers, processors, regulators, and consumers. Based on the utilization of digital technologies, agricultural production can be boosted while minimizing environmental harm. The result is a more efficient transportation and logistics system, improved work conditions for workers, and timely delivery of products that align with consumer needs. Digital agriculture can also address consumer demands for responsible and sustainable production as well as provide evidence of socio-ethical factors and product origin. As per Hackfort [10], digital agriculture refers to digitization that involves the transformation of analog information into digital data, and digitalization is the social process of accepting computer technologies.

Sawant *et al.* [11] mentioned that data science and machine learning are crucial for agricultural data analysis and decision processes in digital farm, noting that data mining, analytics, and data science have significantly benefited digital agriculture. Studies conducted on various agricultural elements have derived models and optimized resource usage and facilitated data-driven analysis for forecasts, resource optimization, and understanding of agricultural processes.

1.4 Entities

1.4.1 Role of Farmers in Digital Agricultural Ecosystem

Digital agriculture has brought significant changes in the way farmers collect and analyze data to improve agricultural production and reduce waste. For digital agriculture to be successful, the active participation of farmers is crucial. Farmers play an essential role in the adoption and implementation of digital technologies, and their feedback and expertise are vital to enhance the effectiveness and efficiency of digital tools and practices.

Farmers play a vital role in the usage of digital tools and techniques as they are often the first entity to try new technology. In this way, farmers can identify any issues or areas for improvement for further enhancement and upgradation [12].

However, farmers also play a proactive role in the construction of digital tools and procedures. By having a close interaction with technology developers, farmers can make sure that digital solutions are easy to use and meet the needs of the agricultural industry.

At the usage level, farmers are responsible for the implementation of digital technologies and practices. It is needed to understand the technology and to modify farmers' current agricultural methods to allow them to use the tools provided by technology developers effectively.

Farmers play a significant role in the collection and analyses of data in the digital agriculture ecosystem. With the use of digital technology, farmers can collect and use vast amounts of data about their farms in order to optimize their farm practices and make data-driven decisions.

However, to use data efficiently in the context of digital agriculture, farmers need specialized knowledge and skills to gather and analyze data. In a rural context, farmers may consider the specific needs of their farm operation, too.

Farmers play a vital role in the development and implementation of sustainable and resilient agricultural practices. The integration of digital technology has the potential to significantly enhance productivity and efficiency in agricultural operations. It is incumbent upon farmers to acknowledge their responsibility in adopting practices that are environmentally sustainable and socially responsible, thereby avoiding any adverse effects on the environment and ensuring the well-being of communities.

1.4.2 Role of Technology Providers in Digital Agricultural Ecosystem

The integration of digital technologies with age-old agricultural practices has given birth to a remarkable era in agriculture, commonly known as digital agriculture. This paradigm shift equips farmers with a diverse range of tools and resources to unlock the full potential of their land, optimizing agricultural productivity, bolstering efficiency, and minimizing the ecological footprint. Within this evolving landscape, technology providers assume a paramount role, leading the charge in developing, designing, and implementing cutting-edge digital solutions tailored to empower farmers and refine their age-old methods [13].

At the heart of the digital agriculture ecosystem lies the crucial responsibility of technology providers: to create and offer a host of digital tools and technologies that seamlessly integrate with farmers' practices, enabling them to unleash the full potential of their agricultural endeavors. Precision agriculture, smart irrigation systems, enhanced crop management systems, and sophisticated data analytics tools are a few of the most noteworthy examples of these disruptive technologies. These revolutionary breakthroughs can assist farmers in making informed decisions that result in improved productivity, efficiency, and sustainable agricultural practices.

Farmers can develop complex maps that allow them to change their agricultural practices with remarkable precision and perfectly address the unique requirements of each crop, by carefully gathering important information on soil conditions, crop growth patterns, and a variety of environmental elements. With the exact application of fertilizers, herbicides, and water supplies made possible by this method, waste is decreased, while yields increase to levels that were previously unattainable.

Empowered by this wealth of information, farmers can effortlessly optimize their irrigation practices, ensuring that water resources are utilized with the utmost efficiency and efficacy.

The implementation of such smart irrigation systems not only contributes to water conservation efforts but also assists farmers in reducing costs while maximizing agricultural yields. Additionally, these solutions prove instrumental in reducing costs while simultaneously bolstering agricultural yields.

Data analytics tools are also instrumental in the digital agriculture ecosystem. Technologies empower farmers to collect and analyze data from various sources, including soil sensors, weather stations, and crop sensors. With this, farmers can build sophisticated models that forecast crop yields, identify potential issues, and receive tailored recommendations on enhancing their agricultural practices.

1.5 Role of Researchers in Digital Agricultural Ecosystem

The role of researchers in the digital agricultural ecosystem is to generate new knowledge and insights that can be applied to improve agricultural practices and productivity. This is related to the development of new digital technologies and the examination and refinement of existing technologies. On the other hand, it is also related to conducting research on the social, economic, and environmental impacts of digital agriculture. Basically, researchers help to ensure that digital technologies are deployed in a responsible and effective way that benefits all the stakeholders related to agriculture.

The researchers' responsibilities include the design and testing of innovative tools such as sensors, drones, machine learning algorithms, and other devices that enable the collection and analysis of data crops, soils, weather patterns, and environmental factors. The utilization of such insights results in improved yields and enhanced profitability for farmers.

Also, researchers have a crucial responsibility to test and refine present digital technologies to ensure their effectiveness across diverse agricultural contexts. In addition to their involvement in the development of digital technologies, researchers also undertake research on the social, economic, and environmental impacts of digital agriculture.

For researchers to excel in their roles, they must possess a profound comprehension of the needs and priorities of farmers and other stakeholders within the digital agricultural ecosystem. Such engagement in terms of dialogue with stakeholders allows researchers to ensure that their research will be utilized to inform decision processes and practical implementation in the agricultural domain.

1.5.1 Role of Policymakers in the Digital Agricultural Ecosystem

Policymakers' unwavering commitment encompasses the formulation of robust regulations that not only foster the widespread adoption of groundbreaking technologies but also guarantee the utmost safety, reliability, and accessibility for farmers.

Policymakers play a crucial role in advancing the evolution of digital infrastructure, encompassing the development and enhancement of essential policies such as financial inclusion, availability of resources, price determination, and community welfare.

In terms of association, policymakers collaborate closely with farmers, academics, and technology suppliers, coalescing their expertise to design inclusive policies that prioritize digital data privacy and security within the agricultural realm. Through stakeholders' active involvement, policymakers contribute to the establishment of a robust legal framework that

safeguards sensitive agricultural data, fostering a conducive environment for innovation and exponential growth in the realm of digital agriculture.

One effective approach involves providing financial support for the development of training programs and instructional materials that equip farmers with the proficiency to effectively navigate the intricacies of digital technologies. Moreover, policymakers may implement a range of financial incentives, including tax breaks and subsidies, as effective motivators to encourage the widespread adoption of digital tools and solutions within agricultural operations [12].

Furthermore, in order to drive transformative change, policymakers forge partnerships with esteemed international organizations such as the United Nations. It helps to harness collective wisdom to foster the utilization of digital technology in agriculture. Collaboratively, policymakers direct stakeholders regarding resources and allocate funds toward cutting-edge research and development initiatives. Such worldwide cooperation aims to spark a significant revolution in the industry, boosting food security and advancement in the socioeconomic growth of countries attempting to overcome agricultural issues.

1.5.2 Role of Customers in the Digital Agricultural Ecosystem

Digital agriculture has opened up new avenues for customer engagement and connectivity with agriculture. Customers encompass individuals and organizations alike who procure agricultural products or services for personal or commercial purposes. Customers as an entity play an integral role in the complex web structure that forms the digital agriculture ecosystem. Their significance lies in their capacity to shape the demand for products and services, thereby exerting influence over the intricate web of the supply chain and the overall functionality of the agriculture sector.

This digital framework facilitates customers' active involvement in various aspects, encompassing investment in agricultural operations, provision of capital for production, acquisition of agricultural produce, and even sharing in the ensuing profits.

Customers further contribute to the agricultural landscape by providing invaluable feedback to farmers and other stakeholders. Leveraging the capabilities offered by digital technologies, farmers can seamlessly collect and meticulously analyze customer feedback. This overall feedback loop provides farmers with an advantageous position in planning their production and pricing strategies, boosting their overall performance and enhancing overall customer satisfaction.

Additionally, digital technologies have acted as a catalyst for direct-to-consumer (DTC) marketing channels, eliminating the need for middlemen and enabling farmers to connect directly with their customers. The prevalence of online platforms and social media also acts as powerful enablers, which allow farmers to sell their produce at competitive rates and also assure that they get a fair and equitable share of the earnings. This innovative approach has found huge success in the digital age as consumers gravitate toward locally sourced, high-quality food products [14].

Customers can influence public policy by promoting environmentally and socially responsible farming practices. Customers can effect change by strongly supporting policy changes that put an emphasis on sustainability and ethical behavior. They can do this by applying significant pressure to lawmakers to enact rules and incentives that would accelerate the general adoption of sustainable agriculture practices. Customers and legislators

working together in harmony have a revolutionary effect that affects the entire agriculture industry and ushers in a new era of progress.

1.6 Elements

1.6.1 Hardware

Hardware encompasses a diverse array of devices, including sensors, drones, robots, GPS receivers, and cameras. These instrumental tools are the main players in terms of efficiency and optimization in agricultural production and in gathering, transferring, and interpreting data.

The hardware's vital role within the digital agricultural ecosystem can be demonstrated by considering its extensive participation in the three key areas of data collection, transmission, and analysis. One instance of how hardware is essential to data collection is the usage of sensors. These cutting-edge instruments are adept at gathering crucial data on nutrient concentrations, temperature swings, and soil moisture levels. Whether they are discretely affixed to plants or deeply submerged in the soil, these sensors operate in real time, flawlessly delivering a continuous stream of valuable information. Drones, which are essential hardware elements for data collection, support this endeavor. Drones use their flying capabilities to acquire high-resolution photographs of crops, enabling thorough crop growth monitoring, disease or pest identification, and evaluation of overall crop health. Additionally, the installation of GPS receivers makes it possible to get exact information about the movement and placement of equipment, providing opportunities for the field operations' optimization.

The hardware plays a crucial part in enabling the data's flawless transmission to the cloud for in-depth analysis after it has been carefully collected. The landscape of digital agriculture attests to the necessity of technology in the field of data transfer. Wireless sensors become crucial partners, transferring the cautiously gathered data across cellular or internet networks, guiding it toward the vast world of the cloud. Additionally, by utilizing their wireless capabilities, drones and robots allow the quick transmission of data to the cloud, significantly increasing the effectiveness of the entire system. In the meantime, GPS receivers accurately communicate location data, making it possible to optimize field operations and hence improve agricultural practices broadly.

The importance of hardware in maximizing the potential of massive datasets has been directly observed in the field of data analysis. High-performance computers and servers diligently analyze vast data, including satellite images and meteorological information, as necessary. In order to help people make well-informed decisions, these computing giants carefully unearth invaluable data regarding crop health and growth trends. GPUs, which serve as accelerators and improve the system's capabilities, greatly speed up the analysis process and ensure quicker, more accurate findings. Hardware accelerators like field-programmable gate arrays (FPGAs), which speed up the processing of certain algorithms like those used in machine learning models, also play a significant role. By overcoming traditional computational limitations, these accelerators shift the paradigm and increase the speed and accuracy of data processing.