2025 Volume 3, Issue 9
Lecture Notes in Education, Arts, Management and Social Science
ISSN(Online): 2705-053X

Driving Factors, Core Challenges and Management Path of Smart Agriculture

Xiangzhi Kong*
Tianjin Agricultural University, Tianjin 300392, China

**Author to whom correspondence should be addressed.*

Abstract: Global agriculture stands at a historic crossroads. Traditional agricultural production models have become unsustainable under multiple pressures, including continuous population growth, tightening resource constraints, and intensifying climate change. Technologies emblematic of the Fourth Industrial Revolution, such as the Internet of Things, big data, artificial intelligence, and robotics, are reshaping agriculture with unprecedented force, giving rise to a new paradigm centered on "smart agriculture." From a management perspective, this paper systematically explores the core drivers of smart agriculture development, thoroughly analyzes its technological architecture and operational models, and focuses on the critical challenges encountered in areas such as technology integration, economic costs, data governance, human resources, and institutional environments. Finally, it proposes a comprehensive management and development pathway aimed at providing theoretical references and practical guidance for relevant stakeholders, including governments, agricultural enterprises, and farmers, to advance the robust, efficient, and sustainable development of smart agriculture.

Keywords: Smart agriculture; Precision agriculture; Agricultural management; Digital transformation; Sustainable development

Online publication: October 26, 2025

1. Introduction

Agriculture is the foundation of human society, and guaranteeing food security and the effective supply of agricultural products is an eternal issue. However, agriculture in the 21st century is facing unprecedented complex challenges: according to the United Nations, the global population will increase to 9.7 billion by 2050, and the demand for food will increase by about 60% compared with the current situation; at the same time, shrinking arable land resources, water shortages, aging labor force and rising costs, environmental pollution, and the frequent occurrence of extreme climatic events have jointly constituted bottlenecks restricting the sustainable development of agriculture. In this context, the traditional agricultural model, which relies on experience, high inputs and sloppy management, shows its limitations.

Smart agriculture, as an advanced stage in the development of agricultural informatization, is a key breakthrough in solving the above contradictions. It is not the application of a single technology, but through the deep integration of a new generation of information technology and the whole agricultural industry chain, to realize the digitalization, networking and intelligence of agricultural production, operation, management and service [1]. Its essence is a complex "technology-management" system, aimed at obtaining better quality, higher yield and more efficient agricultural output with less resource input and lower environmental costs. In this paper, we will start from the systematic thinking of management science, jump out of the mere listing of technologies, focus on the core management issues of strategy, organization, resources and risks involved in smart agriculture as an emerging industry and business model, and provide a structured analytical framework for the understanding and development of smart agriculture.

2. The core driving force for the development of smart agriculture

The rise of intelligent agriculture is not accidental, but is the result of a combination of technological thrust, market pull, policy orientation and resource pressure.

2.1. The strong impetus of technological progress

Internet of Things technology makes farmland, livestock and poultry houses, agricultural machinery, etc., comprehensively perceivable and interconnected, constituting the "nerve endings" of intelligent agriculture [2]. Cloud computing and big data technology for massive agricultural data storage, processing, and analysis provide a "brain." Artificial intelligence and machine learning are empowered in the prediction model, intelligent diagnosis, and decision support, realizing the leap from "perception" to "cognition" [3]. robotics and automation technology replace repetitive, high-intensity human labor, improving the accuracy and efficiency of operations. The maturity and cost of these technologies have reduced the cost. The maturity of these technologies and cost reductions have laid a solid foundation for the commercialization of smart agriculture.

2.2. Structural changes in market demand

The increasing demand for the quality, safety and traceability of agricultural products is forcing agricultural production to transform to transparency and refinement [4]. Through blockchain, RFID and other technologies, smart agriculture can build a full traceability system from field to table, effectively responding to market concerns. At the same time, the trend of personalized and customized consumption also requires agricultural production to have higher flexibility and responsiveness.

2.3. Strategic guidance from national policies

The world's major agricultural powers have placed smart agriculture at a high level of national strategy. For example, China's "digital countryside" strategy, the EU's "farm-to-table" strategy, and the U.S. "precision agriculture" initiative have created a favorable macro-environment for the development of smart agriculture through financial subsidies, project demonstrations, standard-setting, and policy favoritism. Through financial subsidies, project demonstrations, standardization and policy inclination, a favorable macro-environment has been created for the development of smart agriculture.

2.4. Inherent resource and environmental constraints

Water scarcity has forced agriculture to move towards "precision irrigation", where soil moisture is monitored in real time by sensors to realize water supply on demand [5,6]. The hard constraint of the red line of arable land requires that a higher value must be created per unit area, and smart agriculture maximizes land yield through variable fertilizer application, precision seeding and other technologies. There is also an urgent need for environmentally friendly smart solutions to address climate change and reduce surface source pollution from fertilizers and pesticides.

3. The core composition and operation mode of smart agriculture

From a management perspective, smart agriculture is a synergistic system consisting of a technical layer, an executive layer and a decision-making layer.

3.1. Technology architecture: sensing, transmission, analysis and execution

(1) Sensing layer: Includes a variety of sensing devices deployed in the air (drones, satellite remote sensing), sky (weather stations), ground (soil sensors, foliage humidity sensors), and ring (livestock and poultry wearing equipment), responsible for collecting a full range of data on the environment, crops, and animal growth.

(2) Transmission layer: Using 5G, LoRa, NB-IoT and other communication technologies, we build a high-speed, low-power, widely-connected network covering the farm to ensure stable, real-time data transmission.

(3) Platform layer (analysis and decision-making): This is the "brain" of smart agriculture. Based on the cloud platform and agricultural big data, AI algorithms are used to carry out data mining, model construction and intelligent analysis, and generate decision-making instructions such as pest and disease early warning, yield prediction, and irrigation and fertilization prescription charts.

(4) Application layer (execution): Translates decision-making instructions into concrete actions. For example, self-driving tractors apply variable fertilizers based on prescription maps; smart irrigation systems are automatically turned on/off; robots perform precision weeding or automated harvesting.

3.2. Operating model innovation

Intelligent agriculture is driving a systematic change in the operation mode: firstly, it realizes refined operation in the production side, and shifts the management decision from "experience-driven" to "data-driven," and achieves cost reduction and efficiency increase; then, it gives birth to a service-oriented business model, and professional service providers reduce the threshold of technology application for farmers through the pay-as-you-go SaaS service. Professional service providers, through pay-as-you-go SaaS services and other methods, have reduced the threshold of technology application for farmers; ultimately, the vertical integration of the industry chain is promoted, and leading enterprises use this to open up the upstream and downstream, realize quality control and value-added value of the whole chain, and reshape the competitive pattern of the industry.

4. Management challenges and constraints of smart agriculture

Despite its promising prospects, the scaling up of smart agriculture still faces a series of serious management challenges.

4.1. Challenges of technology integration and system compatibility

Intelligent agriculture involves a large number of technology providers, and the data interfaces and communication protocols between different devices and platforms are of different standards, forming "data islands" and "system chimneys" [7]. Farmers need to invest a lot of effort in system integration, which greatly increases the complexity and cost of technology adoption. How to build an open, unified and interoperable technical standard system is the core problem that needs to be solved.

4.2. High upfront investment and unclear return on investment (ROI)

Deploying smart agriculture systems requires huge upfront capital investment, including hardware procurement, software licensing, network construction and system maintenance. For the majority of small and medium-sized farmers, this is a heavy financial burden [8]. At the same time, the high natural and market risks of agricultural production, and the long and uncertain return on investment cycle of smart agriculture, make farmers particularly cautious in their investment decisions. Clear, quantifiable ROI models and feasible financing channels are key to promotion.

4.3. Data security, privacy and ownership issues

Agricultural data is the core asset of smart agriculture. Who owns the data (farmers, service providers or platform providers)? How is the data used? How is its commercial value distributed? How can data be prevented from leakage and tampering during transmission and storage? These data governance issues currently lack clear laws, regulations and industry norms, restricting the full release of the potential of data elements.

4.4. Human resources and skills gap

Intelligent agriculture requires practitioners to be not only capable of traditional cultivation, but also digitally literate, able to operate smart devices and interpret data reports. Currently, the majority of agricultural practitioners, especially older farmers, generally have a shortfall in digital skills. At the same time, there is also a lack of composite talents in rural areas who understand both agriculture and technology. This structural contradiction in human resources is a major bottleneck that restricts the adoption of smart agriculture.

4.5. Insufficient support of infrastructure and institutional environment

The smooth operation of smart agriculture is highly dependent on stable, high-speed rural network coverage and reliable power supply, which is still a shortcoming in many remote areas. In addition, land transfer policies, data legislation, insurance and financial product innovation and other supporting systems related to smart agriculture are not yet perfect, failing to form a good ecosystem to support its development [9,10].

5. Management paths and countermeasures to promote the sustainable development of smart agriculture

In order to meet the above challenges, it is necessary for the government, industry, research institutes and farmers to make concerted efforts to promote the project at multiple levels, including strategy, organization, technology and policy.

5.1. Strategic level: Strengthen top-level design and planning guidance

The government should play the role of “guide” and “enabler.” First of all, the development of national-level medium- and long-term strategic planning for the development of smart agriculture, clear development goals, key tasks and regional layout. Second, accelerate the development of technical standards for data formats, equipment interfaces and platform interoperability to break down information barriers. Finally, promote the establishment of a legal framework for the rights, circulation, trading and security protection of agricultural data, to clear the obstacles to the marketization of data elements.

5.2. Organizational and business model level: Encouraging innovation and collaboration

At the organizational and business model level, a two-wheel drive should be adopted to stimulate the industry’s vitality. On the one hand, we should vigorously explore diversified business models to lower the application threshold, including promoting the AaaS (Agriculture as a Service) model, developing “cooperatives + smart agriculture” to achieve economies of scale, and guiding financial and insurance institutions to develop appropriate credit and insurance products. On the other hand, it actively builds an open and collaborative industrial ecosystem and promotes the formation of industrial innovation alliances among equipment vendors, software vendors, telecommunication operators, agricultural enterprises and research institutes, with the aim of jointly overcoming technological bottlenecks, providing integrated solutions, avoiding fragmented competition at the source, and forming a synergistic force for development.

5.3. Technology and management: focusing on applicability and ease of use

Low-cost and highly reliable solutions can be developed, and technology suppliers should be committed to developing differentiated products that meet the needs of different scales and types of farms, with particular attention to the affordability of small and medium-sized farms. Technology is not the more advanced the better, but the more applicable the better. At the same time, to strengthen the concept of user-centered design, software and hardware design should give full consideration to the use of farmers' habits, simplify the operation process, provide an intuitive and easy-to-understand data visualization interface, and reduce the difficulty of using technology.

5.4. At the human resources level: implementing a large-scale digital literacy program

At the human resources level, a two-wheel drive system covering "stock enhancement" and "incremental cultivation" should be constructed. At the human resources level, a two-wheel drive system covering "stock enhancement" and "incremental cultivation" should be constructed. Take digital skills as the core content of the cultivation of new vocational farmers, through a flexible combination of online and offline, the majority of working farmers for systematic training, to ensure that they master the basic operation and application of smart agriculture, to solve the problem of "not know how to use." In terms of incremental training, deepen the integration of industry and education to reserve future talents. Encourage institutions of higher learning and vocational colleges and universities to open smart agriculture-related professions, and cooperate with enterprises to build training bases, directed to cultivate a number of both understanding of agricultural technology and information technology composite talents for the long-term development of the industry to provide a solid foundation of talent.

5.5. Infrastructure and policy level: Strengthening the foundation of development

Continuously increase investment in digital infrastructure (5G, fiber optics, Beidou navigation, etc.) in rural areas to achieve full coverage. At the same time, improve rural logistics, cold chain and other supporting facilities. In terms of policy, precise subsidies and tax incentives will be given to farmers or enterprises that purchase smart agriculture equipment and services, and priority will be given to supporting land for smart agriculture projects.

6. Conclusion

Smart agriculture represents the future direction of agricultural modernization and is an inevitable choice to meet the challenges of global food security and sustainable development. It is not only a technological revolution, but also a profound management revolution and industrial paradigm shift. It requires agricultural producers to change from "artists" relying on experience to "scientists" based on data, and agricultural management systems to move from decentralized and isolated to integrated and synergistic.

The analysis in this paper shows that the development of smart agriculture is a complex, systematic project, and its success depends not only on technological advancement, but also on the ability to effectively address the core challenges faced by the management level, such as integration, cost, data, talent and system. In the future, we need to adopt a more systematic and ecological perspective, organically combining technology, management, policy and humanities, and gradually overcoming development bottlenecks through multi-party co-creation. Only in this way can we move steadily towards the "farm of the future" that is resource-saving, environmentally friendly, highly productive and profitable, and truly realize high-quality development of agriculture and comprehensive revitalization of the countryside.

Disclosure statement

The author declares no conflict of interest.

References

[1] Cao B, Li J, Van B, 2025, Development Status, Challenges and Prospects of Smart Agricultural Technology in China.

Transactions of the Chinese Society of Agricultural Engineering, 41(21): 1–10.

[2] Feng R, Li S, Hu J, et al., 2025, Research on the High-Quality Development Model and Path of Smart Agriculture in Liaocheng City. Agricultural Equipment and Vehicle Engineering, 2025: 1–6.

[3] Wang C, 2025, Current Situation and Suggestions on the Development of New Agricultural Economy Taking Yantai, Shandong Province as an Example. Time Economics and Trade, 22(10): 153–155.

[4] Li D, Huang G, 2025, The Quality and Quantity of Qingdao's Agricultural Products Have Risen From "A Flash in the Pan" to "Always Red". Qingdao Daily, 003.

[5] Xin H, Chen Y, Qin Z, 2026, Construction of Double Control Evaluation Index System of Total Water Consumption and Intensity Under the Guidance of "Four Water and Four Determination". Journal of Shandong University of Technology (Natural Science), 40(01): 58–65.

[6] Gu Y, Jiang L, Liu Z, 2025, Development Status and Prospect of Agricultural Irrigation Technology. Journal of Smart Agriculture, 5(20): 40–44.

[7] Xie J, Liu J, Tang J, et al., 2025, Digital Empowerment of China's Agricultural and Rural Modernization Development Path: Analysis and Countermeasures. Agriculture and Technology, 45(17): 168–171.

[8] Chan K, 2025, Analysis on Problems and Countermeasures of Smart Agriculture Development: Taking Shenyang City as an Example. Shanxi Nongjing, (18): 108–110.

[9] Sun Q, 2025, The Level Measurement, Regional Differences and Driving Factors of Digital Development of the Whole Agricultural Industry Chain. Journal of Shenzhen University (Humanities and Social Sciences), 2025: 1–10.

[10] Guo H, 2025, Research on the Path of Rural Industrial Revitalization Enabled by New Quality Productivity. Agricultural Economy, (10): 53–55.