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Equipment and Information Collaboration to Promote Development of Modern Smart Agriculture

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Abstract: Agricultural machinery and equipment are the material basis of modern agricultural development and are an important symbol of agricultural mechanization. The new generation of information technology can promote the intelligent transformation and upgrading of agricultural machinery and equipment. The coordinated development of intelligent agricultural equipment and information technology has become a new trend in modern agricultural development, which is of positive significance for improving agricultural production efficiency and promoting the high-quality and efficient development of agricultural machinery. This study compares and analyzes the research status of smart agriculture in China and abroad and summarizes the research progress and trend of agricultural machinery and agricultural information technology in China. Based on an analysis of the development needs and values of modern smart agriculture in China, we propose the following projects: an agricultural ecosystem monitoring network infrastructure; the construction of a national agricultural big data center and operation mechanism; the research and application of intelligent agricultural equipment; the demonstration of agricultural information services; and the development of intelligent sensing technology and equipment for fruit and vegetable commercial processing. To provide a solid guarantee for guiding the development of modern smart agriculture, China should increase agricultural science and technology innovation input, establish an agricultural industry–university–research innovation alliance, and improve agricultural science and technology innovation incentive policies.

Keywords: agricultural equipment; agricultural informatization; agricultural information service; intelligent agricultural machinery; new infrastructure

1 Introduction

The Internet of things (IoT), big data, cloud computing, artificial intelligence (AI), blockchain, and other new generation information technologies are developing rapidly and transforming industrial applications. Modern agriculture is infiltrating and integrating along with them, giving birth to a new business form and model of smart agriculture, which supports agriculture to establish higher productivity, production mode, and economic form [1,2]. Agriculturally developed countries actively plan and deploy cutting-edge technology research and development (R&D), data sharing and opening, and industry talent training, and steadily promote the deep integration of the new-generation information technology and agricultural production [3]. The big data R&D plan, agricultural technology strategy, agricultural development 4.0 framework, and other policy documents have accelerated the development of smart agriculture and the digital agricultural economy [4].

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The manufacturing level, total equipment, and operation level of agricultural machinery in China have achieved rapid development, which has promoted the transformation of agriculture from the previous production mode based on human and animal power to a new stage of mechanization based on mechanical power [5]. Currently, China is the world's largest producer of agricultural machinery, with more than 8000 enterprises in the agricultural machinery and equipment industry (more than 1700 enterprises above the designated size) and approximately 4000 agricultural equipment products. The industrial output value of agricultural machinery enterprises increased from more than 83 billion yuan in 2004 to 450 billion CNY in 2019. However, the agricultural machinery industry is still in its infancy in the research and application of agricultural machinery and equipment automation, information technology, intelligence, and other technologies [6]. It is in the stage of realizing automation based on electronic control technology, while intelligent technology with information technology still needs to be fully developed. During the 14th Five Year Plan period, China urgently needs to accelerate the construction of a smart agricultural technology system, grasp the future development trend, and support the high-quality development of the agricultural industry.

This paper discusses agricultural equipment technology and information technology in depth, as well as the status, effectiveness, and development trends of related technologies. On the basis of studying and judging the development needs of modern smart agriculture and looking forward to future development prospects, our paper puts forward suggestions for the development of key projects in order to provide a basic reference for the sustainable development of smart agricultural equipment and informatization, efficient system optimization, efficient utilization of resources, and other research.

2 Application analysis of equipment technology in modern agriculture

2.1 Power machinery

Power machinery refers to the machinery that replaces human and animal power and provides the motive power for various agricultural machinery and facilities. Its application improves the efficiency of agricultural machinery, enhances resistance to natural disasters, reduces the amount of manual labor, and significantly improves labor productivity and output.

Tractors are the main agricultural power machinery, with the development goal of high efficiency, intelligence, environmental protection, and information integration, focusing on the improvement and optimization of power, transmission, walking, hydraulic pressure, suspension, driving comfort, and other technical directions. Information control technology is mainly developing in the direction of automation and intelligence [7]. The automation and intelligence of tractors are closely related to positioning, dynamic path planning, machine vision, and remote monitoring, involving navigation, images, models, strategies, actuators, data links, and other engineering technologies [8].

In response to the excessive consumption of petrochemical fuels and the aggravation of environmental pollution accompanied by the expansion of agricultural mechanization, the requirements of relevant diesel engine emission regulations are bound to be more stringent. Adopting various internal purification and external tail gas treatment technologies to minimize the emission by the whole machine and developing new alternative energy technologies such as high specific energy power batteries and biomethane fuel power in parallel are necessary to achieve zero emission, no pollution, low noise, and high efficiency during the operation of the unit and solve the problem of energy conservation and emission reduction in the process of agricultural mechanization.

2.2 Field precision operation machinery

Field precision operation machinery is mainly categorized into soil tillage machinery, seeding machinery, field management operation equipment, precision irrigation equipment, combine harvesters, and agricultural waste collection equipment. Taking the tillage depth control of domestic agricultural machinery as an example, the force adjustment and position adjustment methods of tillage machinery are mostly used (Fig.1), which is essentially a simple combination of machinery and a hydraulic system. In the actual operation process, there are problems such as unstable resistance and being unable to monitor in real time. To achieve precise control of tillage depth, an electronic tillage depth control system based on electromechanical hydraulic integration technology should be adopted in the future.

The cultivation and land preparation industry is changing from "function demand" to "quality demand," strengthening the R&D of core technologies such as key parts and materials and processing technology of fine cultivation and land preparation machinery, optimizing the process combination of wide joint cultivation and land

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preparation machinery, and improving the level of automatic monitoring and fault diagnosis, operation depth control, unit level adjustment, and operation speed matching of cultivation and land preparation machinery. It is an important direction for the development of agricultural mechanization to develop intelligent, high-speed, and wide-ranging combined tillage and land preparation machinery that can reduce the number of animals entering the land, save energy, and reduce consumption [9,10].

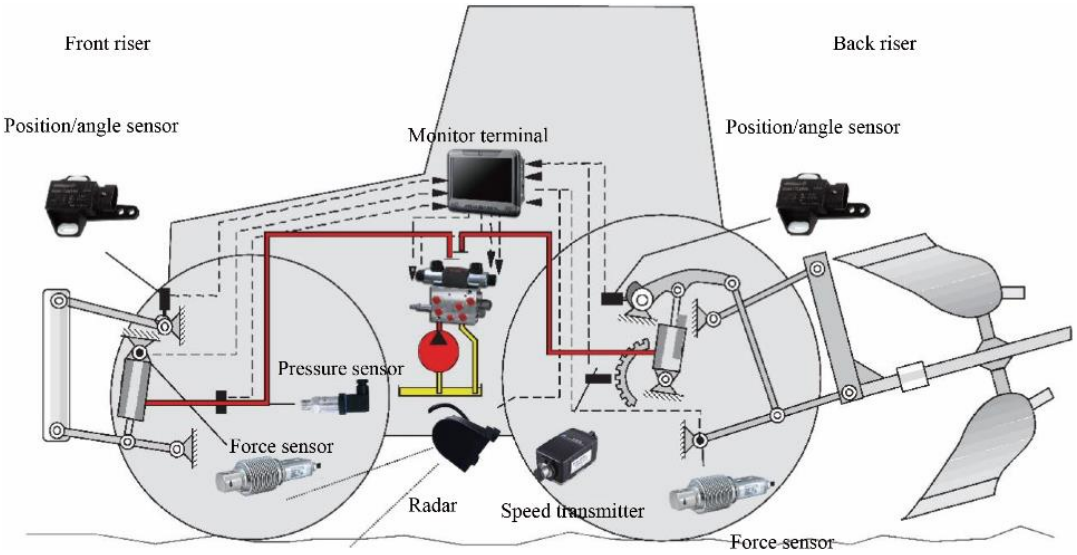

Fig.1. Schematic diagram of the tillage depth control system of tillage machinery.

2.3 Industrialized agricultural equipment

Industrialized agriculture refers to the use of industrialized production methods to provide a suitable growth environment for agricultural organisms, including plants, animals, and micro-organisms, in a relatively controllable growth environment to improve agricultural output, quality, and efficiency and promote the intensive, efficient, and sustainable development of agricultural production methods. It is characterized by balanced production such as annual, all-weather, and anti-seasonal production; high output efficiency such as a high degree of large-scale production; high land output rate; high labor productivity; and high resource utilization rate; high product value, including high-quality safety; high degree of commercialization; and high market adaptability.

The core equipment of industrialized agriculture is mainly categorized into industrialized facility design and manufacturing, intelligent sensing and sensing equipment, intelligent control equipment, and precision operation equipment [11]. At present, the industrialized planting facilities in China include solar greenhouses, plastic greenhouses, multi-span greenhouses, and artificial light plant factories. The monitoring equipment based on information perception includes sensing monitoring, spectral monitoring, and video monitoring, which forms a multi-source information coupling sensing mode. The monitoring method has developed from offline laboratory measurement to portable multi-parameter measurement and then to real-time online measurement. It provides key technical support for standardized assembly line operation by quickly extracting all kinds of information required for the precise operation of industrialized plant actuators. The developed countries of protected horticulture represented by the Netherlands have developed mature and stable equipment and systems for the environmental regulation of facility temperature, humidity, CO_2, light, and so on. Notably, China has reached an advanced level in the ability and innovation of facilities as well as environmental control technology and equipment, and developed a greenhouse environment integrated control system based on positive pressure ventilation (Fig. 2), an energy transfer heating system between greenhouses based on dual heat source heat pumps, a greenhouse environment integrated control cloud platform, and an optimal control decision algorithm based on the environmental crop coupling model. However, the greenhouse environment control strategy and control system are still weak links in the development of protected horticulture in China.

In the future, intelligent operation equipment technology should strive to achieve breakthroughs regarding the key technologies of crop production, postharvest, logistics, and other links under the condition of unmanned control and thus realize the combination of AI, big data, intelligent equipment, and agronomy [12]. This can be done by

forming intelligent operation technology equipment covering the application of the entire industrial chain, such as crop seedling robots, logistics robots, plant protection robots, harvesting robots, postharvest treatment equipment, and agricultural waste treatment robots. By integrating mechanical, electronic, control, and other technologies, we can develop biosensor equipment for real-time monitoring of plant physiological and ecological characteristics, maximize access to plant growth demand information, reduce human impact, and comprehensively carry out scientific production and information management [13].

Fig. 2. Greenhouse environment integrated control system based on positive pressure ventilation.

2.4 Primary processing equipment of agricultural products origin

The primary processing equipment for agricultural products in the production area is mainly categorized into grain drying equipment, pre-cooling and fresh-keeping equipment for fresh agricultural products, and non-destructive testing and grading equipment for agricultural products. The corresponding equipment has gradually developed from mechanization to intelligence and automation.

Grain drying equipment focuses on technical breakthroughs in high efficiency, high quality, energy conservation, intelligence, and so on. On the basis of enhancing the awareness of the importance of pre-cooling and fresh-keeping equipment for fresh agricultural products, we can steadily improve the reliability and detection accuracy of non-destructive testing and grading equipment for the quality of agricultural products. Primary processing equipment for agricultural products will play a key role in ensuring the quality and safety of agricultural products and improving the market competitiveness of agricultural products, driving agricultural production to be more efficient and comfortable. Thus, agricultural resources will be used more fully and in an environmentally friendly manner.

3 Application analysis of information technology in modern agriculture

Agricultural information technology research in China began relatively late, and its evolution can be divided into four stages: embryonic (late 1970s–early 1980s), growth (1980s–early 1990s), mature (early 21st century–around 2010), and 4.0 (after 2011). After more than 40 years of development, a relatively complete technical system has been formed in the field of agricultural information [14,15].

3.1 Crop information acquisition technology

Crop phenotypic information acquisition technology mainly uses automatic platform equipment such as sensor equipment, wireless communication, database, big data analysis, and information technology means to systematically and efficiently acquire phenotypic information such as crop multi-scale traits (tissue, organ, plant, population), including the original data of crop phenotype formed by the interaction between gene and environment, the top data of crop phenotype, and the complete set of biological knowledge. According to the difference in the experimental environment, phenotypic information acquisition technology can be indoor and outdoor. The former accurately regulates various environmental factors, strictly controls the growth conditions of crops in growth boxes or greenhouses, and carries out accurate hierarchical simulation and targeted research on crop growth and development under complex experimental conditions. These advantages are difficult for the latter to replicate.

Phenotypic information acquisition and intelligent analysis technology are the key aspects to promoting agricultural digitization and intellectualization, leading the future direction of agricultural development. The future development trend of phenotype technology is aboveground phenotype to underground phenotype, macro phenotype to micro phenotype, physical phenotype to physiological phenotype, and static phenotype to dynamic phenotype.

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This study focuses on the key technologies such as multi-sensor spatio-temporal synchronous acquisition, multi-modal data fusion processing; and real-time online analysis to address the problems of single means of collecting crop phenotypic information and insufficient timeliness of phenotypic data analysis [16]. Additionally, we build a series of crop phenotype platform products with independent technology, reliable and stable performance, the ability of independent operation, and automatic processing to support China's plant phenotype research to enter the advanced ranks in the world.

3.2 Agricultural intelligent knowledge service technology

Agricultural intelligent knowledge service technology takes agricultural knowledge as its content and organizes decentralized agricultural knowledge and data intelligently, using knowledge sharing and a comprehensive auxiliary decision-making model to provide personalized and accurate services for the majority of users to alleviate the problems existing in agricultural production and operation, such as low efficiency of resource utilization, excessive application of water and fertilizer, shortage of experts, and limited knowledge dissemination [17]. By describing agricultural knowledge completely, normatively, and accurately, and storing the data and relationships of agricultural knowledge in the form of an ontology knowledge map, we can realize the real-time, efficient reuse and sharing of agricultural knowledge.

Many agricultural industry classifications, significant regional differences in climate, rapid changes in seasonal production demand, and other characteristics make users' service needs considerably different. Traditional knowledge services have gradually developed into a service model that combines big data drive and knowledge guidance, as represented by the agricultural expert system in the United States in the 1990s. China has formed a series of agricultural expert decision-making systems since 2000, involving the diagnosis, cultivation, and management of diseases and pests of wheat, tobacco, rice, flowers, fruit trees, and horticultural crops, but there are limitations in the construction, updating, and maintenance of the knowledge rules.

The field of agricultural intelligent knowledge service technology is gradually evolving from data mining and statistical analysis of traditional small samples to intelligent analysis and early warning models of massive data, a digital simulation of animals and plants, and process modeling. The Internet is expanding to the IoT, and thus, agricultural intelligent knowledge services can integrate machine learning, modeling and simulation, cloud computing, image recognition, complex networks, geographic information systems, and other technical means so that many problems and events in the agricultural field can be simulated and solved. Representitive technologies include the intelligent extraction technology of agricultural knowledge driven by multi-modal data, the adaptive analysis model of agricultural big data based on deep learning, and the cross-media agricultural knowledge association understanding and service interaction mechanism.

3.3 Intelligent management technology of agricultural production

The intelligent management of agricultural production involves multiple departments, fields, and disciplines with outstanding systems and complexity, and can be divided into intelligent crop production, intelligent livestock and poultry breeding, and intelligent aquaculture according to industrial fields. The intelligent management technology of crop production refers to accurately adjusting various management measures and material inputs according to the specific conditions of each field operation unit under the condition of mastering the land resources and crop population variation to pursue the optimal economic benefits and reduce the environmental risks brought by agricultural production [18]. Specifically, it can be divided into precise fertilization, precise irrigation, precise pesticide application, agricultural situation consultation, and decision-making and command. Among them, the IoT technology is based on the collaborative operation of intelligent equipment to realize the real-time perception and transmission of agricultural production information; big data and cloud computing are used for the digital storage, analysis, and operation processing of agricultural production information; and AI technology is used to mine knowledge from massive data and analyze and judge problems in agricultural production to provide decision support [19].

Taking the intelligent management technology of livestock and poultry breeding as an example, through the new generation of information technologies such as the Internet, big data, cloud computing, blockchain, sensors, image processing, sound recognition, and other advanced sensing and monitoring technologies, we can carry out intelligent management of livestock and poultry breeding environments, accurate feeding management of livestock and poultry, intelligent diagnosis and early warning prediction of livestock and poultry diseases, comprehensive information management of livestock and poultry breeding, digital management of livestock and poultry genetic breeding, and

quality safety management of livestock products, realizing intelligent production, networked operation, accurate management, and standardized mode. In the future, unmanned or few people smart pastures can be realized, which cover weighing, stocking, feeding, drinking water, and other links, intelligent and precise health management, precise prediction of oestrus, automatic feeding, and pasture management. This technology can minimize the risk of livestock and poultry being infected by epidemic diseases owing to human contact and integrate key technologies such as genetics, precise nutrition, environmental control, production management, and biosafety.

3.4 Intelligent circulation technology of agricultural products

Intelligent circulation of agricultural products mainly involves information acquisition technology of the circulation environment, quality perception technology of agricultural products, and transportation and distribution route optimization technology of agricultural products [20]. The purpose of obtaining circulation environment information is to strictly control the temperature, humidity, light, oxygen content, ethylene content, hydrogen sulfide content, and other environmental parameters of food in the cold chain circulation process of agricultural products, especially in the long-distance transportation process. For the distribution of refrigerated vehicles with a single temperature zone and a single product, the real-time collection, transmission, and storage of environmental information in the vehicle are completed through sensors.

The quality perception of agricultural products is key to ensuring the quality and safety of cold chain food [21]. Food quality is divided into appearance, physical, nutritional, safety, and sensory quality. For this purpose, rapid non-destructive testing technology has been developed, involving mechanical, electronic, optical, electrochemical, biological, and other methods. It can be subdivided into smell, taste, visual sensor technology, spectral analysis technology, and biosensor technology.

Agricultural products transportation and distribution path optimization refer to enhancing the information acquisition and application, process optimization, and other capabilities of cold chain logistics enterprises through the mining, processing, and analysis of massive data to provide a basic information platform for the construction of the IoT for agricultural products cold chain logistics. Most theoretical studies transform the multi-objective optimal distribution path selection problem into a single objective optimization problem according to weighted summation, model construction, analysis, and application. In the actual distribution process, swarm intelligence algorithms can substantially solve the multi-objective optimization problem of the optimal distribution path based on the optimal solution corresponding to the biased goal.

4 Analysis of the development value of modern intelligent agriculture in China

4.1 Development needs

Intelligent agricultural equipment technology with satellite positioning, intelligent control, IoT, mobile Internet, big data, and other information technologies as the core is the direction of the future development of agricultural machinery and equipment. Agricultural machinery equipment technology in China has gone through the stage of machinery replacing human and animal power, and the comprehensive level of products has made great progress. However, there is still a big gap compared with agricultural machinery power. With the development and deepening application of information technology, traditional agricultural production in China is changing to modern agriculture, and traditional agricultural machinery will develop into intelligent agricultural equipment that is deeply integrated with the new generation of information technology.

It should also be noted that the research on automation, informatization, intelligence, and other technologies of agricultural machinery and equipment in China is still in its infancy, and there is an urgent need to benchmark industrial applications, increase investment, and maintain high-speed development. In combination with the national food security strategy and the requirements of sustainable agricultural development under the new situation, the agricultural equipment field has created an action plan to promote agricultural science and technology innovation and accelerate the popularization and application of agricultural science and technology around the major development needs of developing modern agriculture and urban and rural planning. Research on intelligent equipment technology for precise operation in the main links needs to be carried out by facing the actual situation of intelligent and precise production in the production links of major food crops and cash crops, facility agriculture, animal husbandry, processing and utilization of agricultural waste, and the characteristics of agricultural production and agronomic requirements in various regions. Finally, developing intelligent technology and equipment systems of agricultural machinery as soon as possible and effectively promoting the transformation of agricultural production

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from extensive management to intensive management is necessary to evolve from traditional to modern agriculture.

4.2 Application prospects

The green and sustainable development of agriculture is an act of preserving green waters and mountains and building a beautiful China, which is of great significance to ensure sustainable development. The comprehensive construction of a green ecologically oriented scientific and technological innovation system for sustainable agricultural development will not only activate the endogenous driving force of agricultural development but also promote the effective restoration of agricultural ecosystems, cleaner production environments, significantly increased green supply capacity, and improved resource utilization efficiency.

The modern intelligent agricultural technology system will become the backbone of agricultural modernization in China. The modern seed industry and equipment technology represent intelligent and ecologically integrated solutions that are widely used in planting, aquaculture, and other fields, and they are the primary driving force in promoting the transformation and upgrading of agricultural industrial structures. By 2050, high and new technologies such as biology, information, and equipment will promote the transformation and upgrading of the modern agricultural industry in China, and the proportion of agricultural applications of information technology and intelligent equipment is predicted to exceed 50%. Major breakthroughs have been made in the level of agricultural mechanization and facilities and equipment, and three major changes have been achieved, namely "machines replace manpower," "computers replace the human brain," and "independent technology replaces imports."

In the field of field planting, mechanization, informatization, and intellectualization have become the basic characteristics of mainstream applications. By 2050, the integrated application of advanced technologies such as information, life sciences, key equipment, and nutritional improvement in the production of bulk crops will be fully realized. In terms of facilities and industrialized agriculture, intelligent and independent decision-making has become the mainstream, and intelligent greenhouses, plant factories, and space agriculture have been applied on a large scale. The comprehensive efficiency of agricultural production has reached an internationally advanced level [22]. In terms of livestock and poultry breeding, the integrated application of intelligent facilities and equipment, big data, and AI technology has become the main way. By 2050, the intellectualization of precision feeding, intelligent feeding, automatic cleaning, and epidemic prevention and control will be fully realized, a green ecological intelligent breeding system will be formed, and production efficiency and quality control will be significantly improved.

5 Key projects to ensure the development of modern smart agriculture

5.1 New infrastructure project of agricultural ecosystem monitoring network

Currently, China's agricultural system mainly adopts ground survey and statistics, fixed-point observation, and agricultural remote sensing monitoring, and the sky–Earth integrated monitoring technology framework has been preliminarily constructed and put into application. However, the application level of sensor real-time and automatic monitoring equipment is not high enough to realize the rapid monitoring of the whole agricultural industry chain, including production, circulation, and service. The digitalization level of agricultural production is only 18.6%, and the number of self-developed agricultural sensor applications is less than 10% of the world's [23]. The agricultural ecosystem monitoring infrastructure is weak compared with the applications of powerful agricultural countries and other domestic industries. The means are single, and the accuracy of the monitoring results is insufficient. Moreover, the lack of a comprehensive and three-dimensional monitoring and evaluation network makes it difficult to support the optimal allocation of the whole industrial chain and all factor resources guided by ecological goals.

Therefore, we should build new infrastructure for the three-dimensional monitoring network of agricultural ecosystems that integrates satellites, unmanned aerial vehicles, mobile communication base stations, and sensors; establish a national smart agriculture R&D team; and strengthen the R&D of core technologies such as real-time perception, intelligent analysis, and intelligent decision-making. In addition, we should consider the improvement of agricultural production efficiency as a direct goal, take into account the control objectives of agricultural non-point source pollution and greenhouse gas emissions, and build ecologically oriented smart farms, smart fisheries, and smart pastures.

5.2 National agricultural big data center and operation mechanism construction project

We should implement the national strategy of agricultural big data and build a national agricultural big data center, including an agricultural big data collection network, an agricultural big data storage platform, an agricultural big

data processing platform, and an agricultural big data comprehensive analysis platform. We should optimize the top-level design, implement unified standards, distributed storage, centralized control, and reasonable opening, and collect overall, regional, and professional data, including priority planting, breeding, agricultural machinery, seed industry, cultivated land, science, education, and typical agricultural products. Additionally, we should build a "one map" based on big data, covering agricultural production factors, environmental factors, and industrial layout, carry out innovative applications based on agricultural big data, and integrate the three industries of the agricultural sector, improving production scheduling, decision-making, management, and service capabilities.

Furthermore, we should promote the development of agricultural data standardization and sharing mechanisms; develop data resource management measures, data production specifications, and data sharing mechanisms relating to data links such as collection, storage, sharing, circulation, use, and security; and create an institutional foundation for agricultural data collection, application management, and open sharing. We should focus on agricultural applications, clean, integrate, integrate and mine agricultural big data, study data mining and analysis, animal and plant ontology models, agricultural and rural application scenarios of big data, form the capabilities of agricultural data association prediction and multidimensional simulation of agricultural data early warning, and improve the accuracy of agricultural monitoring and early warning. Considering data asset security, data compliance risk, and data production efficiency, we should build a prevention and control system for data flow risk, balance data flow and data security issues, and improve the collaborative governance ability of all stakeholders. Finally, we should put forward the software and hardware infrastructure of key information, apply national standards, and enhance the traceability and security early warning ability of physical data flow.

5.3 Research and application engineering of intelligent agricultural machinery and equipment

Intelligent agricultural machinery technology takes the application of satellite navigation as its core and integrates the functions of sensors, big data, decision support, and so on. Therefore, it is necessary to research the aspects of intelligent sensors, intelligent navigation, precision operation, operation management, and so on [24]. (1) Based on the technology and product capabilities of sensitive materials and core chips, we should research and develop special intelligent sensors for agricultural machinery and equipment for information transmission of body performance, environmental status, and operation conditions. (2) Using technologies such as unit positioning and satellite-based enhanced navigation, we should develop an intelligent navigation system for agricultural machinery and equipment, improve the accuracy and stability of agricultural machinery navigation, and ensure the automation level of agricultural machinery and equipment. (3) We should carry out real-time analysis of the operation process of agricultural machinery and equipment, research on intelligent agricultural machinery decision-making and control, establish and verify the intelligent and precise operation technology of agricultural machinery and equipment, realize the functions of precise sowing, intelligent irrigation, intelligent fertilization, and improve the level and quality of agricultural machinery operation. (4) We should track and apply information technology, conduct research on intelligent operation and management of agricultural machinery and equipment, realize the functions of remote intelligent regulation, intelligent early warning, intelligent diagnosis, and collaborative operation of agricultural machinery and equipment, improve agricultural machinery and equipment operation and management efficiency.

5.4 Agricultural information service demonstration project

Agricultural information services mainly rely on intelligent technical means to provide high-quality information service capabilities for the agricultural supply chain, including production, storage, transportation, and sales, and improve agricultural production efficiency and market competitiveness. It is an important way to promote agricultural supply-side reform and a strategic choice to achieve sustainable agricultural development. Agricultural information services in China have entered the primary stage of intelligent agricultural information services, but there are still phenomena such as insufficient data sharing and data analysis and mining capabilities, mismatching between supply and demand of information services, and unreasonable resource allocation. Therefore, there is a strong demand for agricultural productive services based on reliable information transmission and in-depth information analysis. Therefore, we should develop agricultural information service projects based on new-generation information technology, promote the deep integration of big data technology and agricultural productive services, guide agricultural production, and provide precision services through innovative data applications [25,26].

Furthermore, we should promote the Broadband China strategy, support the extension of new infrastructure projects such as fifth-generation mobile communication to agricultural and rural areas, providing infrastructure support for agricultural information services. According to the characteristics of ecology, decentralization, variety,

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and planting and breeding methods of agricultural regions, agricultural information service pilot demonstrations should be carried out in the form of agricultural industrial parks at all levels, agricultural science and technology parks, and key agricultural product production bases. For new rural agricultural business entities, we should integrate cross-media, massive, and fragmented agricultural information knowledge through in-depth learning methods, establish a comprehensive agricultural knowledge center, and provide efficient, convenient, concise, intuitive, and two-way interactive agricultural knowledge active services. Additionally, we should create a unified intelligent agricultural information service platform, cultivate professional information service organizations (both online and offline), and provide services such as real-time transfer of agricultural machinery resources, agricultural materials information, agricultural arrangements, crop plant protection, pest control guidance, agricultural insurance, and skill training. Finally, we should improve the service subject status of enterprises, support agricultural information service enterprises to provide intelligent solutions and services in the field of agricultural production services, and build a diversified service system aimed at meeting the diversified and personalized information service needs of agricultural business entities.

5.5 Demonstration project of intelligent sensing technology and equipment R&D for commercialization of fruits and vegetables

Compared with developed countries, the development of the cold chain logistics system in China started late, and there are still deficiencies and hidden dangers in the management and operation mode of cold chain logistics, the regulatory system of laws and regulations, and the infrastructure and hardware facilities, such as the cold chain breaking, the fluctuation or uneven distribution of environmental temperature and humidity, and the opacity of cold chain flow. As a result, the loss rate of postharvest apples in the cold chain circulation process, including postharvest pre-cooling, transportation, storage, and sales, is as high as 15–25%. Improper operation of refrigeration conditions in each link of the cold chain or the lack of a seamless connection guarantee between each link (i.e., chain breaking) will affect the stability of the fruit required for the low temperature and high humidity environment, thus affecting the uniformity and stable distribution of the wind field, temperature field, and humidity field in the ventilation box in the cold chain circulation, resulting in the decline of fruit quality. Therefore, clarifying the interaction mechanism between the fluctuation of temperature and humidity in the cold chain and the deterioration of fruit quality is of great significance to improve the uniformity of temperature and humidity distribution in all links of the cold chain and ensure the safety of fruit quality.

Given the current situation of low-end commercialization of fruits and vegetables in China, we should carry out technical research on data collection, perception, control, maturity prediction, and quality sorting of fruits and vegetables in the process of pre-cooling, sorting, packaging, storage, distribution, and other key operations. We should also build a mathematical model for accurate prediction of storage and shelf life of fruits and vegetables and establish a supporting intelligent prediction technology. We should put forward the standard procedures for accurately judging the maturity of large and characteristic fruits and vegetables in China and formulate intelligent grading standards for fruits and vegetables. Additionally, we should research and develop supporting equipment for intelligent sensing technology for the commercialized processing of fruits and vegetables and establish a modern intelligent equipment and technology demonstration base for the commercialization of fruits and vegetables.

6 Countermeasures

6.1 Increasing investment in agricultural science and technology innovation and optimizing the structure

For a long time, agricultural science and technology investment intensity in China has been low, and the structure is unreasonable. It is suggested to further increase the scale of modern intelligent agricultural science and technology investment and optimize the structure of science and technology investment. Owing to its public welfare and exclusivity, agricultural scientific and technological innovation produces more social benefits than private benefits. To overcome the “free rider” problem, it is necessary to give full play to the guiding role of the government and reasonably increase financial support for the innovation, transformation, and promotion of modern smart agricultural science and technology under the new market conditions. It is suggested to establish a special fund for scientific and technological innovation in modern smart agriculture to support the scientific and technological breakthrough of cutting-edge technologies in agricultural production and to support the technical driving and demonstrative role of major agricultural scientific research achievements. International experience shows that private R&D investment and public R&D investment are complementary. It is suggested to formulate relevant incentive measures to guide

social organizations and agricultural enterprises to actively carry out modern smart agricultural science and technology innovation research to form a stable agricultural science and technology investment mechanism and diversified investment pattern.

6.2 Establishing an agricultural industry–university–research innovation alliance

The industry–university–research innovation alliance is an important organizational form of agricultural production mode under the background of the knowledge economy, which is conducive to the complementary advantages and resource coordination of different innovation subjects, lengthening the innovation value chain and building the core competitiveness and innovation ability of modern smart agriculture. It is suggested that scientific research institutes, colleges, and management departments should participate together, highlight the main role of agricultural enterprises, reconstruct the modern agricultural science and technology innovation system in China, give play to the preset utility, and form a cooperative relationship through the innovation value chain. They should also provide enabling policies in finance, taxation, and other areas; improve the benefit distribution mechanism of the alliance's various innovation subjects; accelerate the transformation and upgrading of agricultural industrial structures; and stimulate the driving force of the agricultural science and technology innovation system. Furthermore, they should implement the strategy of invigorating agriculture through science and technology by increasing the training of agricultural scientific research talents, cultivating new groups of farmers, building a diversified talent incentive mechanism, improving human capital reserves, and giving sufficient support.

6.3 Improving the incentive policies for agricultural scientific and technological innovation

Agricultural scientific and technological innovation has uncertainties and risks. One of the reasons for the lack of agricultural scientific and technological innovation in China is the lack of motivation. It is suggested to analyze the development characteristics of modern smart agriculture and improve the incentive policy system for agricultural scientific and technological innovation. Maintaining reasonable government procurement support is also necessary, especially to support major innovative achievements in modern smart agriculture. Diverse investment subjects should be encouraged to participate in modern smart agriculture innovation activities, boost agricultural science and technology investment enthusiasm, assist agricultural practitioners in actively utilizing innovative achievements, and simultaneously strengthen agricultural intellectual property rights protection. Private capital should be guided toward participating in agricultural enterprise innovation activities and improving the ability of enterprise innovation to resist risks. Additionally, a platform must be created to transform agricultural scientific and technological achievements; enrich information exchange channels; and reduce market information asymmetry, all of which are conducive to the transformation, commercialization, and industrialization of modern smart agriculture's scientific and technological achievements. The assessment and evaluation system of agricultural science and technology should be improved to comprehensively evaluate the academic value, application feasibility, and industrial applicability of agricultural scientific research achievements. Finally, the organic combination of the agricultural science and technology chain and the agricultural industry chain must be promoted, and the enthusiasm of scientific researchers should be stimulated in the form of sharing the excess output of science and technology.

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