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Development Strategy of Agricultural Big Data and Information Infrastructure

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Abstract: Agricultural big data and information infrastructure are important foundations for modern agriculture and prerequisites for smart agriculture, and represent new elements for promoting agricultural growth in a new era. In this article, we analyze the development status and existing problems of China's agricultural big data and information infrastructure, considering the strategic needs and challenges of smart agriculture development. We also summarize the relevant policies, action plans, and experiences in China and abroad, propose strategic objectives for developing agricultural big data and information infrastructure in 2025, 2035, and 2050, and devise a future development technology roadmap. In the future, big data development should be promoted across the entire agricultural industry chain, and the construction of an agricultural big data system should be standardized by building an integrated data sharing mechanism. The breakthroughs achieved in key common technologies can expand the applications of agricultural big data. In general, agricultural big data industry bases should create application clusters for agricultural big data. An urban–rural integrated information infrastructure should be built by coordinating urban and rural resources, along with an agricultural cyberspace for providing interconnections between everything (e.g., human–computer interactions); in addition, an integration of space–sky–land–sea is expected to be created. From a policy perspective, China should strengthen its overall planning to improve its rural network infrastructure and the digital transformation of traditional infrastructure, along with promoting the basic research and development of chips, model components, and basic information systems. Moreover, it should focus on core technologies such as those for facilitating agricultural big data acquisition, analysis, and service, strengthen the collaborative innovation in systems and mechanisms to achieve the standardized and integrated sharing of agricultural data, and build a high-level talent team to provide basic support for developing smart agriculture in China.

Keywords: agricultural big data; information infrastructure; technical route; smart agriculture

1 Introduction

Agricultural big data refers to the practice of applying big data concepts, technologies, and methods in the field of agriculture [1]. After entering the era of big data and information, agricultural big data and intelligent analysis technologies have developed into novel modern agricultural production elements, allowing agricultural

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practitioners to discover new knowledge, create new value, improve production capacity, and provide new and important strategic resources [2]. Agricultural big data can provide a fresh impetus for the transformation and development of agricultural and rural economic structures, with the constant changes in agricultural production, operation, and management services means as its basis [3]. The phase "agricultural information infrastructure" refers to the basic information hardware, application terminals, and basic equipment for facilitating the informatization of public services for agriculture and rural areas, including agricultural data acquisition facilities, agricultural data storage and computing power, agricultural and rural network communications, agricultural information application terminals, and agricultural informatization integration infrastructure. Agricultural big data and information infrastructure are important foundations for the development of modern agriculture and the fundamental premise for the construction of smart agriculture; this, they play important roles, i.e., as a bridge and/or cornerstone.

New infrastructure has given rise to a new phase in the information revolution. Many countries have developed big data, fifth-generation mobile communication (5G), and other new-generation information technologies and infrastructure elements as prior actions for the strategic deployment of plans. For example, the United States has launched strategic plans, including Big Data Research and Development Plan, National Broadband Plan, and the Connecting America Fund. Meanwhile, the United Kingdom has launched an Agricultural Technology Strategy, Germany has issued an Industrial 4.0 digital agenda (2014–2017) and the Digital Strategy 2025, etc., and Japan has launched a Future Investment Strategy [4–7]. In recent years, China has attached considerable significance to actively promoting the construction of agricultural big data and information infrastructure. It successively released the *Broadband China Strategy and Implementation Plan*, *Action Plan for Promoting Big Data Development*, *Agricultural and Rural Big Data Pilot Plan*, *Strategic Outline of Digital Rural Development*, and *Digital Agricultural and Rural Development Plan (2019–2025)*, among others. The *14th Five-Year Plan for National Economic and Social Development and 2035 Outline of Long-range Objectives of the People's Republic of China* proposed accelerating the construction of a national integrated big data center system, building of several national hub nodes and big data center clusters, and hastening of the development of smart agriculture. The implementation of a series of documents, major decisions, and deployment plans will further promote the development of China's agricultural big data and information infrastructure. In academic research, domestic researchers have conducted a series of studies on key technologies [8], platform architectures [9], and applications [10,11] for agricultural big data. Overall, China's agricultural big data technology and applications have developed rapidly. Considerable progress has also been achieved in space–sky–land big data acquisition, big data modeling analysis prediction, data-driven intelligent decision-making, and so on. The application of big data covers the entire process of the agricultural industrial chain.

2 Development status of agricultural big data and information infrastructure

2.1 Agricultural information monitoring technologies, transmission technologies, and computing technologies have been significantly improved, and agricultural information infrastructure has been continuously perfected

With the in-depth implementation of the Broadband Village and other strategies, China's agricultural information infrastructure has seen significant development in terms of its data acquisition capacity, data resource construction, data computing power, agricultural and rural network communication, and application terminals.

Agricultural data monitoring technology has continuously improved. China's first agricultural high-resolution observation satellite was successfully launched into orbit and put into operation in 2018, thereby breaking the long-term dependence of China on foreign suppliers for high-resolution Earth observation data. In terms of sensors for the ground Internet of Things, a batch of low-cost and practical agricultural sensors have been produced and used for meteorology, soil, water, plant life information, physiological and biochemical information, animal behavior recognition, and so on, and play important roles in agricultural information monitoring and data acquisition [12]. Space–sky–land digital agricultural technology has been gradually formed; in one study, an integrated observation system was established through the comprehensive use of space remote sensing, aerial remote sensing, and the ground Internet of Things to achieve high-resolution, three-dimensional, and continuous acquisition of agricultural information [13]. The construction of the national agricultural big data acquisition system has been continuously improved, making full use of the Internet of Things, intelligent equipment, mobile Internet, and other information technologies to acquire agricultural and rural data, and to improve the efficiency

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and quality of data acquisition. The basic agricultural database has been gradually established and improved to realize centralized and unified management of the basic agricultural survey data. The agricultural product market information platform has become an agricultural big data resource pool, comprising the entire industry chain data of 15 key agricultural products in eight categories, including grain, cotton, oil, sugar, livestock and poultry products, aquatic products, vegetables, and fruits. In general, 1×10^5 elements of new data are added daily, and in total, approximately 2×10^9 elements of agricultural data have been accessed. The database has become a central gathering of China's agricultural product market information data [14].

Agricultural and rural network facilities have also continuously improved. As an initial step, a ubiquitous, safe, and green broadband network environment was built in China. Urban optical fibers were provided to buildings and families, and rural broadband was provided to villages. Nevertheless, an era of the same network and same speeds in rural and urban areas is approaching. The Internet penetration rate in rural areas has steadily increased. By the end of 2020, the penetration rate of the Internet in rural areas in China was 55.9%, whereas that in urban areas was 79.8%. Thus, the gap in the penetration rate of the Internet between urban and rural areas has narrowed significantly [15]. Over 98% of China's administrative villages have opened both optical fiber networks and fourth-generation mobile communication (4G). Globally, China leads in the coverage of rural networks [16]. Broadband access users in rural areas have increased rapidly. By the end of 2020, the total number of rural broadband users in China reached 1.42×10^8 with a year-on-year growth of 5.3%, and the corresponding users accounted for 29.3% of the total number of Internet access users [17]. With the integration of national cable television networks and integrative growth of 5G construction for radio and television, radio and television have also become accessible to families in rural areas.

The computing capacity for managing agriculture has also continuously improved. After years of constant accumulation, China has achieved significant progress in the field of artificial intelligence (AI). China is among the top countries in terms of the numbers of scientific papers published internationally and invention patents authorized, and breakthroughs have been made in certain core and key technologies. Technologies such as adaptive autonomous learning, intuitive perception, integrated reasoning, hybrid intelligence, and swarm intelligence are capable of leapfrogging development. Intelligent monitoring and biometric identification are gradually being applied in practical applications. Novel and highly efficient algorithms have promoted AI innovation and entrepreneurship [18]. With the in-depth integration of agriculture and AI technology, and based on continuous innovative research and development (R&D), high-performance algorithms and intelligent models have been effectively applied for intelligent decision-making in all links of the entire industrial chain, such as in agricultural production, circulation, and markets [19]. Agricultural big data computation research has focused increased attention on finding correlations from massive data to make prediction analyses. Agricultural data processing is evolving from traditional data mining, machine learning, and statistical analysis to intelligent analysis and early warning model systems.

New agricultural infrastructure construction has also been initiated. The construction of agricultural and rural big data centers and other new infrastructure has also been accelerated. New technologies, new products, and new business forms of digital agriculture have continued to emerge. Applications for Beidou, 5G, the Internet of Things, agricultural sensors, and intelligent equipment have also gained momentum, thereby promoting the rapid development of smart agriculture. The development of 5G has entered a phase of comprehensive and in-depth implementation [20]. The integrated innovation and application of 5G in agriculture has attracted increased attention across the country. Innovative practices in the operation modes of smart agricultural demonstration parks based on 5G have emerged as well. For example, the Yangling Demonstration Zone in Shaanxi has actively promoted 5G information construction, and has built an agricultural big data management center and agricultural production and operation control system based on the Internet of Things and 5G technology. The Nanjing National Agricultural High-tech Industrial Demonstration Zone in Jiangsu has cooperated with the Jiangsu Branch of China Mobile on a plan for realizing full 5G+4G coverage in the zone within three years, aiming to inject new digital momentum into agricultural technology innovation. 5G enables information entering villages into families, 5G+ agriculture-benefitting e-commerce live broadcasts, 5G+ intelligent breeding, 5G+ intelligent planting, and 5G smart agricultural machinery, and other highlights have constantly emerged. The digital transformation of traditional rural infrastructure has also accelerated. The digital reconstruction and upgrading of the rural power grid, intelligent water conservancy, rural logistics, agricultural machinery, and equipment have also increased. A map of the national water conservancy has been established, along with corresponding basic attributes and an e-map database of national rural roads. The digitization of agricultural machinery and equipment is currently being

accelerated, and the application of Beidou terminals has expanded continuously.

2.2 Breakthroughs have been made in agricultural information standardization, acquisition, analysis and processing, management, and other technologies, and remarkable achievements have been made in the construction of agricultural big data

China's agricultural big data are undergoing long-term and sustainable growth. Massive data resources are continuously being produced for agricultural resources (e.g., atmosphere, soil, water, and biomass), agricultural environments (e.g., meteorology, hydrology, soil moisture, temperature, and humidity), agricultural crops (e.g., crop growth, yield, diseases, and pests), agricultural processes (e.g., breeding, fertilization, harvesting, transportation, and sales), and many other aspects.

A complete big data standardization framework has been established. Standardization and normalization are the basic guarantees for the rapid analysis and application of big data [21]. In 2014, the National Information Technology Standardization Technical Committee established a big data standardization group responsible for formulating, revising, and perfecting big data standards and specifications. This system was proposed to include basic standards, data standards, technical standards, platform/tool standards, management standards, safety standards, and industry application standards [22]. Based on extensive research and investigation, the Chinese Academy of Agricultural Sciences has analyzed the actual situations and requirements in the current standardization and normalization of agricultural big data, and has provided suggestions regarding the standardization framework for agricultural big data [23]. Statistical results have shown that a total of 6575 relevant standards and norms have been issued by the Ministry of Agriculture and Rural Affairs, covering agricultural foundations, agricultural machinery, processes and technologies, environmental requirements, product standards, grade and specification, food safety, quality inspection, disease prevention and control, labeling, and other categories, thereby providing methodological guidance for the acquisition, analysis, and application of agricultural big data.

Effective data management norms and multi-level rural and agricultural big data centers have been developed. From the construction of the Jinnong Project in 1994, and after years of development and improvement, China has formed a multi-level agricultural big data system. The Ministry of Agriculture and Rural Affairs, together with other relevant departments, has promoted the development of agricultural big data. Focusing on agricultural resources and environment, agricultural production, agricultural product processing, and market operation, 23 sets of statistical investigation systems (more than 300 statements in total, 5×10^4 indicators) have been successively established, and 18 data marts with themes addressing the output, price, import and export, cost, and income of the main agricultural products have been formed, with approximately 3×10^5 daily updates [24]. At present, the Ministry of Agriculture and Rural Affairs is organizing and constructing agricultural and rural big data centers and implementing a national platform. The China Seed Industry Big Data platform has integrated four levels of seed industry management data (country, province, district (city), and county levels), and has synchronously collected industrial data for variety approval, registration, protection, and promotion. A total of 2.4×10^5 agricultural technicians have been gathered in the China Agricultural Technology Promotion Information Platform. The number of platform requests has exceeded 3×10^9 [25]. The Guizhou Department of Agriculture and Rural Affairs has established an agricultural big data management platform with more than 20 agricultural information service systems in operation online, including systems for animal disease monitoring, soil resource management, agricultural product quality traceability, agricultural condition scheduling, and purchases of agricultural machinery. The big data platform of the Bohai Granary Science and Technology Demonstration Project has a diversity of massive data sources, multi-factor comprehensive analysis and decision-making, and other functions for effectively guiding the grain production management and decision-making process in the region; it covers 30 counties and 1.5×10^7 *mu* of grain fields (1 *mu*≈ 666.67 m^2) [26]. The Agricultural Information Institute of the Chinese Academy of Agricultural Sciences has developed and established the China Agricultural Monitoring and Early-Warning System. The system covers big data resources for production, circulation, and the entire industrial chain of important agricultural products, supports monitoring and early warnings for the agricultural market, and releases the *China Agricultural Outlook* annually [27].

A series of agricultural big data technology application modes have been developed. Agricultural big data have been integrated with the Internet, cloud computation, AI, and other information technologies to change traditional agricultural modes and promote the development of smart agriculture. In terms of efficient breeding, big data mining, artificial neural networks, deep learning, and other AI technologies have been employed and deeply

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integrated with modern biotechnology to explore excellent genes and accelerate the independent innovation of the entire breeding chain. In terms of agricultural production management, data regarding the environmental factors collected during production, growth of animals and plants, and other issues have been analyzed and processed. The goals of improving efficiency and increasing income are being achieved through the implementation of the scientific and precise control and optimization of agricultural production. In terms of monitoring the agricultural product market, the collection, analysis, release, and service technology systems for the information of the entire industrial chain of agricultural products (as supported by big data) have provided effective market information services for the main body of agricultural production and operation, thereby promoting the accurate docking, production, and sales of agricultural products. In terms of rural management services, agricultural big data have been combined with a sharing economy to integrate and exchange resources based on an Internet Plus big data platform, aiming to ensure maximal and optimal accurate matching between rural resources and rural tourism consumption needs, and to promote the high-quality development of leisure agriculture and rural tourism [28]. In addition, software and hardware carriers for intelligent decision-making systems, information push services, mobile intelligent terminals, other data services, and related big data service applications have gradually gained popularity in the agricultural field.

3 Major problems in the construction of agricultural big data and information infrastructure

3.1 Rural network infrastructure remains weak

China’s information infrastructure has made a series of important achievements, but still faces some issues, including the lagging construction of rural network infrastructure, significant differences between urban and rural digital development, a lack of information infrastructure for planting and breeding bases, and insufficient integration of traditional infrastructure and informationization. Compared with cities, the penetration and access speed of fiber broadband in rural areas and proportions of Internet users in rural areas are much lower. By the end of 2020, the difference in the penetration rate of the Internet between urban and rural areas remained at 23.9%. Thus, the large gap in digital penetration between urban and rural areas has not yet been eliminated. The questionnaire survey data issued in one study showed that the proportion of planting and breeding bases accessing optical fiber networks was 27.2%, whereas the proportion of peasant households using information terminals to monitor or control the planting and production of crops was approximately 13.6%; the proportion of network speeds of bases unable to meet the demands for agricultural applications was 19.7%. The low proportion of peasant households accessing the Internet, low proportions of planting and breeding bases accessing optical fiber broadband, and poor Internet signals have restricted the popularization and application of smart agricultural technology.

3.2 Insufficient capacities for agricultural data acquisition, analysis, application, and sharing

The digital resources in China are scattered. The space–sky–land integrated data acquisition ability is not strong, and the coverage is low. A large gap can be observed between the domestic sensor technology and the level of technology worldwide. The current digital, intelligent, and miniaturized technology products have serious shortcomings. The analysis and application of agricultural data remains insufficient. Moreover, considerable restrictions on the values of data elements can still be found. Many agricultural big data platforms remain at the level of data acquisition, rough processing, and phenomenon demonstration. In the last kilometer of agricultural and rural areas, grassroots agricultural service enterprises docking directly with small peasant households usually do not have big data platform R&D technologies or big data analysis and mining abilities. There are many barriers to agricultural data sharing, and sharing remains seriously insufficient. Increased amounts of data are protected as personal or departmental wealth. The development and utilization levels, owing to data exclusivity or monopoly, remain low. The legal protection mechanism for agricultural data sharing is imperfect. Most agricultural-related departments follow a principle of cautious sharing, i.e., refusing the open sharing of important agricultural data, leading to low-value elements in the shared agricultural data, and difficulty in meeting the needs of smart agriculture.

3.3 Insufficient original innovation abilities for key core technologies

The original innovations in intelligent perception, high-throughput acquisition, AI chips, and other core

technologies are now insufficient. High-end computing chips and technical standards are still being monopolized by foreign countries, and addressing the situation of being controlled by others remains difficult in the short term. Bottlenecks in chip design and manufacturing, large-scale industrial software, mobile operating system basic software, and other aspects can still be observed. The level in China is still far from reaching the world's advanced level in terms of novel computing platforms, distributed computing architecture, big data processing, analysis, and representation. The R&D on forward-looking technologies are in a follow-up state, and the influence of big data core technologies and ecosystems is weak overall [29]. The key technological innovations in agricultural big data cannot be separated from the breakthrough and development of these basic information technologies. The key technologies are sealed in developed countries, making it difficult to buy. Most basic technologies and equipment are bought from abroad, and independent R&D is difficult. Therefore, it is necessary to continue to increase investments in basic R&D for agricultural big data.

3.4 Professional talent team needs to be expanded

The industry lacks specialized personnel. Although large amounts of agricultural-related data have been accumulated, massive amounts of data are in a sleeping state owing to a lack of professional data processing, analysis, and mining personnel. In-depth applications have not yet been realized. The fields of big data and agriculture still lack compound personnel. Talented individuals in the field of computers often do not understand agriculture, whereas agricultural personnel often do not understand information technology, especially big data technology. Compound personnel with interdisciplinary professional knowledge are scarce. The grassroots information teams are insufficient, and lack regular professional training and necessary financial support. The teams are unstable, and the number and quality of personnel engaged in related jobs fail to meet the requirements for information development in the new era.

4 Development goal and roadmap of agricultural big data and information infrastructure

4.1 Development goals

The construction of agricultural big data and information infrastructure can be promoted based on national conditions, agricultural conditions, and practical needs. The agricultural information infrastructure will achieve localization as a whole, and the gap in the network between urban and rural areas will be eliminated. A network space with the interconnection of all things, human–computer interactions, and space–sky–land–sea integration will be formed. Breakthroughs will be made in the key core digital technologies for agriculture, and an agricultural digital economy system will be built. A national data sharing and exchange network will be gradually formed to realize integrated and standardized data sharing. The application of agricultural big data is continuously being deepened and innovated, aiming to establish a space–sky–land–sea integrated digital agricultural system. An agricultural big data industrial base and industrial application ecosystem will be formed, as jointly established and shared by the government and market. The modernization of agricultural and rural governance systems and governance abilities will be realized. The development roadmap for the agricultural big data and information infrastructure is shown in Fig. 1.

4.1.1 Goals by 2025

The agricultural and rural information infrastructure system will be established and perfected, and a basic data resource system will be established. The space–sky–land–sea integrated observation network and national agricultural and rural big data centers will also be formed. A panorama of national agricultural and rural digital resources will be initially formed to realize the opening and sharing of data resources, and to strongly support the application of smart agriculture in various scenarios. The goal of the broadband penetration is to reach 100% of the administrative villages in China. 5G innovative application will be implemented, and the digital gap between urban and rural areas will be significantly narrowed. The proportion of applications of agricultural information terminals will increase greatly, and the penetration rate of the Internet in rural areas will reach 70%. The proportion of applications of the agricultural Internet of Things will reach 25%. The coverage of village-level information service stations will reach 90%. Rural information services and digital governance systems will be established and perfected.

An agricultural big data standardization technology and data exchange mechanism system will be formed, and an integrated national data sharing and exchange network will be established. The construction of a standards and

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specification system will be strengthened, and agricultural data standards, norms, and security systems will be built to promote the intellectualization and institutionalization of agricultural data management. A 1+*N* data sharing mode (that is, one agricultural big data center, *N* sub-data service centers, and *N* innovative application demonstration bases) will also be established. The industrial data barriers in the field of agriculture will be broken to realize internal, external, horizontal, and longitudinal data sharing in agricultural departments, so as to enable the data to better serve agriculturally associated bodies. An agricultural big data application demonstration base will be established to enrich innovative applications of big data for agricultural production, operation, management, and service.

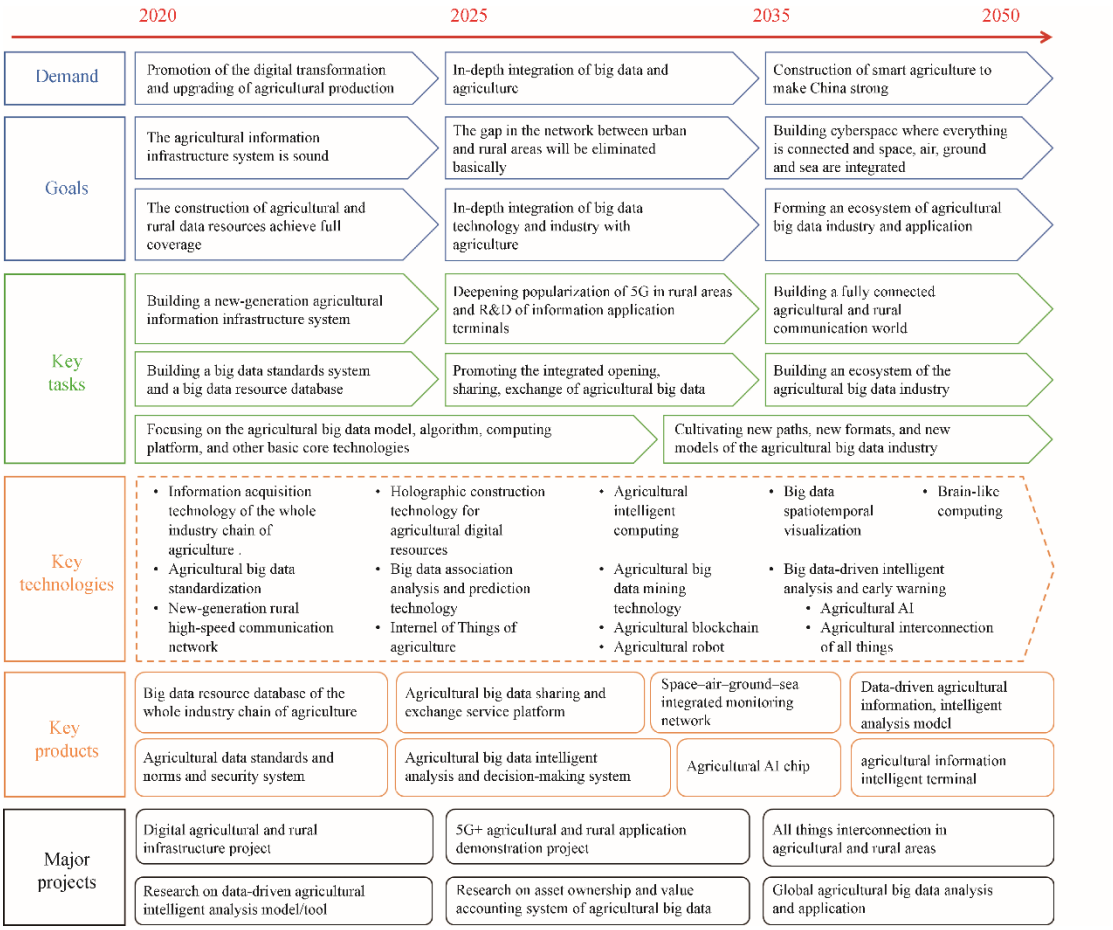

Fig.1. Roadmap of agricultural big data and information infrastructure.

4.1.2 Goals by 2035

Autonomous control of the localization of the agricultural information infrastructure system will achieved. Rural 5G will be popularized and expanded. A sixth-generation mobile communication (6G) network will be innovatively applied. The gap between urban and rural areas will be eliminated, thereby strongly supporting the development of smart agriculture and the achievement of remarkable results in rural development. Brain-like computing, biometric identification, digital twinning, simulation, and other key core technologies and products will make breakthroughs and be widely used. Information terminals will play a significant role in serving peasants in production, operation, management, and life. The penetration rate of the Internet in rural areas will reach 85%. The proportion of applications of the agricultural Internet of Things will reach 35%. The coverage of village-level information service stations will reach 100%. Peasants' digital literacy will be significantly improved, and the equalization of basic public services in urban and rural areas will be realized.

Agricultural key core digital technologies will make great breakthroughs, and an agricultural digital economy system will be built. The standardization and integrated sharing of agricultural data will be realized. The space–sky–land–sea integrated digital agricultural system will be established to realize full-element, full-field, and full-process digital management of agriculture, and to modernize agricultural and rural governance systems and governance abilities. Big data will be deeply integrated with production, circulation, market, processing, and all

links of the entire industrial chain. The application of agricultural big data will be continuously deepened and innovated. New paths, new formats, and new models in agricultural industry development will provide diversification. Big data application products will be continuously enriched, and an agricultural big data customized service mode will become popular.

4.1.3 Goals by 2050

The goals comprises building a new generation of high-speed, mobile, safe, and ubiquitous agricultural and rural information networks and forming a space–sky–land–sea integrated cyberspace with the interconnection of all things and human–computer interactions, thereby laying the important foundation for becoming a powerful nation in smart agriculture worldwide. The penetration rate of the Internet in rural areas will reach 95%. The application proportion of the agricultural Internet of Things will reach 50%. Agricultural and rural information terminals and agricultural robots will support the large-scale and in-depth application of smart agriculture.

The relevant actors in agricultural production, circulation, markets, and the entire chain will realize intelligent digital management. An agricultural big data industry base jointly built and shared by the government and market will be built to attract upstream and downstream enterprises in the agricultural big data industry chain, aiming to settle down and form an agricultural big data industry application ecosystem.

4.2 Key tasks and technical routes

4.1.1 Before 2025

A new-generation agricultural information infrastructure system will be built under the guidance of agricultural and rural digital infrastructure construction. Space-based remote sensing, sky-based, land-based, and marine platforms, as well as other multi-perception systems, will be comprehensively used to build a national agricultural and rural information standards monitoring system. Urban and rural big data centers and other information infrastructure will be used to establish a unified, open, and shared national agricultural and rural big data center. The deployment of agricultural and rural 5G networks, digital infrastructure, and other new agricultural infrastructure will accelerated, and 5G construction will be comprehensively promoted to cover qualified key towns and agricultural parks. A pilot layout and/or innovative applications of the 5G network in rural areas will be executed to narrow the digital gap between urban and rural areas.

In terms of the research, development, and application of agricultural big data technology, agricultural data standards, norms, and security systems will be established to promote the intellectualization and institutionalization of agricultural data management, and agricultural data standards systems such as data collection indicators, acquisition methods, analysis models, and release systems for the entire agricultural industry chain will be built to integrate and gather data from agricultural-related departments. This will facilitate the establishment of an agricultural big data resource center for adapting to agricultural development in the new era. To implement the special R&D of data-driven agricultural intelligent analysis models/tools, R&D will be conducted to provide special tools for the intelligent analysis and processing of agricultural big data, to develop a deep learning model and high-performance algorithms based on agricultural big data, and to build several data-driven intelligent analysis and decision-making systems.

4.2.2 2026–2035

Uses of advanced sensors for agriculture, agricultural AI chips, agricultural high-performance models and algorithms, and other key core technologies will be developed to overcome difficulties in human–computer interaction, biometric identification, brain-like computing, and other aspects, aiming to significantly improve the computing power of agricultural big data. R&D will be conducted on advanced agricultural information infrastructure systems with independent intellectual property rights, so as to guarantee the information safety of the agricultural information infrastructure. A panorama of agricultural and rural digital resources covering the whole country will be built to digitize the agricultural and rural resources across the country. 5G+ agricultural and rural application demonstration projects will be implemented to deepen and popularize the coverage of 5G networks in rural areas, and to establish a smart agricultural technology system supported by 5G. A pilot layout and innovative applications of the 6G network in rural areas will be studied and deployed to reduce the gaps in the network between urban and rural areas. The industrial application of information terminals and agricultural robots will be strengthened and promoted, so as to play a more significant role. The penetration rate of the Internet in rural areas and application proportion of agricultural Internet of Things will be promoted to equalize urban and rural basic public services, and to modernize rural governance systems and governance capacity.

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A space–sky–land–sea integrated digital agricultural system will be built, and a full-element, full-field, and full-process digital management system for agriculture will be promoted. An integrated agricultural and rural data-sharing mechanism will be built to aid in data development sharing, and to continuously deepen and innovate the applications of agricultural big data. A 1+ *N* data-sharing mode will be established, and an agricultural big data sharing and exchange service platform will be built to break the industrial data barriers in the field of agriculture and address the waste of resources caused by different data standards (and by small data centers built by various departments themselves). Issues in data intelligent computing, analysis, mining, deep learning, data visualization, and other key technologies will be addressed by deeply integrating big data and new-generation information technologies with traditional agriculture, cultivating new paths and new formats, and providing a new model for the development of the agricultural industry. An agricultural big data application demonstration base will be established to integrate big data with modern agricultural development, agricultural production management, agricultural resources, ecological environment management, agricultural product safety management, agricultural product transaction and circulation, the monitoring and prediction of agricultural markets and consumption, agricultural innovative services, and other aspects. Thus, the innovative applications of big data in agricultural production, operations, management, and services will be enriched.

4.2.3 2036–2050

A space–sky–land–sea integrated cyberspace will be built with the interconnections of all things and human–computer interactions in agricultural and rural areas, and an agricultural and rural communication network will be established that combines satellite communication, ground communication, and marine communication to lay an important foundation for becoming a powerful nation in smart agriculture. Breakthroughs in agricultural intelligent computing technologies and algorithms will be sought to drive the computing power of agricultural big data to reach a cutting-edge level. A domestic alternative AI chip suitable for agricultural scenarios will be created to drive the wide and in-depth application of such intelligent chips in agriculture and rural areas. High-speed, mobile, safe, and ubiquitous agricultural and rural information infrastructure will be built to realize seamless network coverage in rural production and living areas. A human–machine–thing fully connected agricultural communication digital world will be created through the implementation of an all-things interconnection project in agriculture and rural areas, and applications of agricultural and rural information intelligent terminals will be promoted for spatial communications, intelligent interactions, mixed reality, and other scenarios, aiming to support the large-scale and in-depth application of smart agriculture.

Digital and intelligent management for agricultural production, circulation, the market, and the whole chain will be promoted, and an agricultural big data industry base and agricultural big data industry ecosystem will be established to incorporate agricultural production full-process management, agricultural resources and ecological environment management, agricultural product full-chain safety management, agricultural product transaction and circulation, monitoring and prediction of the agricultural product market, and agricultural information services. This will help the development of intelligent production in agriculture, disaster monitoring and prevention, monitoring and early warnings based on information from the entire agricultural industry chain, agricultural product quality, and safety, along with a series of big data application products. An agricultural big data industry base will be jointly built and shared by the government and the market, i.e., to rapidly form an industrial cluster through the operation of the agricultural big data industry base, and to perfect an agricultural big data industry ecosystem.

5 Countermeasures and suggestions

5.1 Strengthening the top-level design and overall layout, and planning the framework work path for agricultural information infrastructure and big data for middle- and long-term development

Faced by the need to build smart agriculture for a powerful nation and the main battlefields of modern agriculture construction, including strengthening the top-level design and planning the framework and work path of the agricultural information infrastructure and big data for middle- and long-term development, the focus should be on adjusting measures to local conditions, making breakthroughs in key points, and step-by-step promotion. The national administrative department in charge of agriculture should take the lead with the participation of agricultural research institutes, enterprises, and operators, so as to establish a national agricultural big data alliance for jointly studying and formulating top-level design and implementation plan(s) for agricultural big data. To build a basic framework for the application of agricultural big data, an agricultural big data standards system should be

implemented, along with system design and overall planning for data sharing, data storage, data governance, laws and regulations, and other aspects. Urban and rural data centers and other information infrastructure resources should be comprehensively and uniformly planned, along with the construction of new infrastructure for agriculture and urban networks, and an urban–rural integrated information infrastructure. A comprehensive policy system should also be implemented to drive upgrades and ensure sound development in agricultural information infrastructure.

5.2 Strengthening investments in technology research to achieve breakthroughs in key core technologies regarding agricultural big data

Basic research on agricultural big data, enhancement of original and leading scientific and technological research, implementation of key core technological research projects of agricultural big data, and perfection of the strategic layout for the scientific and technological power of agricultural big data should all be encouraged. With the aims of agricultural data acquisition, analysis, application, and other key links, focus should be given to R&D on big data acquisition, massive data storage, data cleaning, analysis, and mining, big data visualization, big data intelligence, big data deep learning, virtual reality, and other key technological directions. In addition, R&D on information intelligent decision-making systems for agricultural production, circulation, the market, and the whole industrial chain should be strengthened, and an advanced agricultural big data technology system should be formed. R&D on original models and advanced algorithms should also be strengthened, and an agricultural big data model development platform should be built for conducting R&D with animal and plant growth models, agricultural product market models, other key mechanism models, and analysis and early warning models, and for improving the efficiency of agricultural information monitoring and early warning systems (as supported by big data). The formation of a market mechanism for agricultural big data applications should be promoted to guide the main bodies of the market to conduct value-added and common technological innovation and to provide service applications for agricultural big data.

5.3 Strengthening the collaborative innovation of systems and mechanism to solve the problems in data sharing and data services

A co-construction and sharing mechanism for agricultural big data resources should be established to drive government-led and market-oriented (and other types of) mechanisms, make overall planning based on confirmation of data property rights, sharing mechanisms, laws and regulations, and other aspects, and to solve urgent problems such as the serious data barriers among agriculture-related management departments and weak awareness of data resources. In terms of the construction of data resources, additional attention should be paid to the collection of basic agricultural data and daily data, the release of long-term and stable policies on data collection supporting subsidies, and platform facility maintenance. A benefit affiliating mechanism should be created for all participants to explore an effective way for the government and social main bodies to cooperate in the construction of agricultural big data, and to guide social capital to actively participate in the construction of agricultural big data through cooperation between the government and social capital, service outsourcing, and other modes. The statuses of the output subjects, service subjects, and application subjects of agricultural big data should be respected, and the marketization mechanisms for agricultural big data transactions should be accelerated. The data benefit allocation mechanism should be perfected, and the confirmation of data property rights, audits of data values, data transaction systems, and regulations should be encouraged to effectively mobilize the enthusiasm of all parties, improve the level of market-oriented operations, and promote the commercialization of agricultural big data achievements.

5.4 Strengthening the construction of a high-level talent team, and promoting China's agricultural big data technology to the forefront of the world

First, China should build a multi-level talent system for agricultural big data, and establish an agricultural big data talent team based on integrating the R&D of common technologies, breakthroughs in key technologies, and the promotion and application of agricultural big data. Second, the training of high-level talent should be strengthened; professional and compound talents in the agricultural big data field should be cultivated, and a high-level talent training and selection platform should be built. The platform should focus on cultivating and supporting the leaders in agricultural big data disciplines and the construction of innovation teams, forging the excellent skills of talent teams aiming at the international scientific frontier and the major needs of the country,

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improving the breakthrough abilities of major core technologies, providing planning abilities for the strategic frontier, and facilitating the ability to solve practical industrial problems. Third, strengthening the training of grassroots informants on big data knowledge will give full play to the roles of big data technology in agricultural and rural management services and other aspects. Fourth, China should strengthen international exchanges and cooperation, establish a cooperation mechanism for cross-border and cross-field flexible exchanges of talent, create an agricultural big data talent think-tank and an industry–university–research alliance system, and encourage normalized innovation achievement exchange and talent exchange mechanisms, so as to continuously provide the endogenous driving force for the innovation and application of agricultural big data.

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