Chapter 12
Practice, Promotion and Perspective of Smart Agriculture in China

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1 Introduction

Compared with the United States (US), Australia, and most European Union (EU) countries, China has a larger number of farmers, but lower scale of agricultural management. The average size of a farmland in the US is over 200 hm^2, with an average area of over 113 hm^2 per farmer. In the EU, 82% of farms are over 20 hm^2, 52% of them over 100 hm^2 in area. In contrast, 95% of Chinese farms are less than 3.4 hm^2 in area, and these account for over 80% of the total national cultivated land (Zhao, 2021). In recent years, with the acceleration in urbanization, China's rural population is showing a trend of reduction, an aging labor force, and an increase in per capita cultivated land area. The small scale and limited capacity of farmers constrain their production efficiency and profitability. Smart agriculture is an important measure to solve these problems by confronting the diminishing advantage of population-driven economic growth and the resources and environment constraints (Klerkx et al., 2019). Smart agriculture is gaining popularity with its significant economic impacts reflected in increasing crop output, reducing labor intensity, and expanding farm size (Charania & Li, 2020). For instance, large-scale smart production management in Beijing could reduce the labor, water, fertilizer, and medicine use by 55%, 25%, 31%, and 70%, respectively (Zhao et al., 2021). It can also help promote smart technologies and maintain sustainability in agriculture (Hassina et al., 2019). Policies promoting smart agriculture have been proposed by the Communist Party of China's (CPC) central committee and the State Council in their annual

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Central No. 1 Document since 2012. Smart agriculture has become a component of China's modern agriculture following the 14th *Five-Year Plan (2021–2025) for National Socioeconomic Development and the Outline of Long-Term Objectives by 2035* adopted by the National People's Congress on March 11, 2021. A variety of other official documents have been issued to promote smart agriculture in China.

Many studies have focused on smart agriculture in China from the technical perspective, including climate-smart (Liang et al., 2021; Tong et al., 2019; Wang et al., 2018), internet (Zheng et al., 2022), and cloud (Yang et al., 2022) services. The other topics considered vary from general status and practice to path selection and policy suggestion, economic effect, and international comparison. Using macro statistical data and a national survey, Song (2020) and Cao et al. (2021) summarize the features, problems, and promotion strategies of smart agriculture in China. In the context of rural revitalization, Zhao et al. (2021) summarize the macro demand for high-quality science and technologies and the strategies and route of China to reach its smart agriculture development goal by 2035. Liu et al. (2021) examine the impact of smart agricultural production investment (SAPI) announcements on shareholder value using sampled data of 118 listed companies in China from 2010 to 2019. Ma et al. (2020) explore the smart agriculture path of China in a comparative analysis with Japan.

In summary, few studies have comprehensively reviewed the policy framework of smart agriculture in China integrating the present status, perspective, and policy suggestions. This chapter tries to fill the research gap in this regard as follows. Section 2 summarizes the definition and components of smart agriculture from the perspective of Chinese academics, discusses the extension rate and domestic industry chain, and presents a case study of smart agriculture in Zhejiang Province. Section 3 reviews the national and local policies for the promotion of smart agriculture in China. Section 4 examines the opportunities and problems of smart agriculture and the countermeasures suggested. Section 5 concludes the study, presenting the major findings and promotion features of smart agriculture in China.

2 Smart Agriculture

2.1 Definition and Components of Smart Agriculture

2.1.1 Concept and Features of Smart Agriculture

Smart agriculture originated from the agricultural informatization of developed countries after their industrialization and agricultural mechanization. This can be traced back to the soybean disease diagnosis system of plant/DS invented by the University of Illinois in 1978 (Michalski et al., 1982). According to a research report of smart agriculture development in China released by CAICT and CARD (2021), smart agriculture is defined as a new agricultural production mode and comprehensive solution deeply integrating the new generation information technology with decision-making, production, circulation, and trading.

Chinese scholars summarized smart agriculture into the following five features (Cao et al., 2021; Kang et al., 2019; Song, 2020): (1) Digitization of information perception: Using certain underlying information acquisition technologies such as Internet of Things (IoT) and 5S,[1] smart agriculture applies big data in decision making for agricultural production and management. Thus, man, machine, and things are connected in different processes to automatically perceive and accurately identify various agricultural elements, information, and environments. (2) Scientific management of decision-making: This is carried out with a highly integrated model using big data, machine learning, and artificial intelligence (AI), among other technologies. This model promotes personalized services such as quantitative analysis and investment in agricultural management. (3) Intelligent control: An intelligent network integrates AI and IoT to promote the automatic, intelligent, and unmanned operation of equipment. (4) Precision investment: A quantitative decision-making model helps to accurately optimize the resource allocation in each agricultural process and improve investment efficiency through reduced costs and consumption. (5) Personalized information service: A big data platform supplies diversified information for the benefit of agricultural business entities. Smart agriculture is a new business model and industry that will reshape the production, supply, and industrial chain. Thus, smart agriculture has great potential in the field of high-quality, efficient, green, and safe development (CAICT & CARD, 2021).

2.1.2 Components of Smart Agriculture

The fields suitable for smart agriculture in China and other countries include precision production, economic benefit accounting, food safety, and electronic commerce. Smart agriculture forms a closed loop that starts with complete and accurate data acquisition. Thereafter, a network provides a pipeline for the flow of data, taking scientific and accurate analysis as the core, and accords efficient execution by the end of the closed loop (CAICT & CARD, 2021).

Smart agriculture mainly uses the next generation information and communication technologies (ICTs), represented by the following elements (Fig. 1). (1) Big data: A database on temperature, air humidity, wind speed, wind direction, sunshine, precipitation, crop growth, irrigation and fertilization, field management, disasters, soil characteristics, and facilities useful for mining and analyzing the relationship between variables and optimizing agricultural production (Huang et al., 2018). (2) IOT: An information aggregation platform based on the interconnection of various sensors, radio frequency identification (RFID), and other electronic terminals. Its core component and foundation are still the internet, but it highlights the automatic interconnection between terminals and business applications (Yang, 2019).

[1] "5S" refers to remote sensing technology (RS), geographic information system (GIS), global positioning system (GPS), digital photogrammetry system (DPS), and expert system (ES).

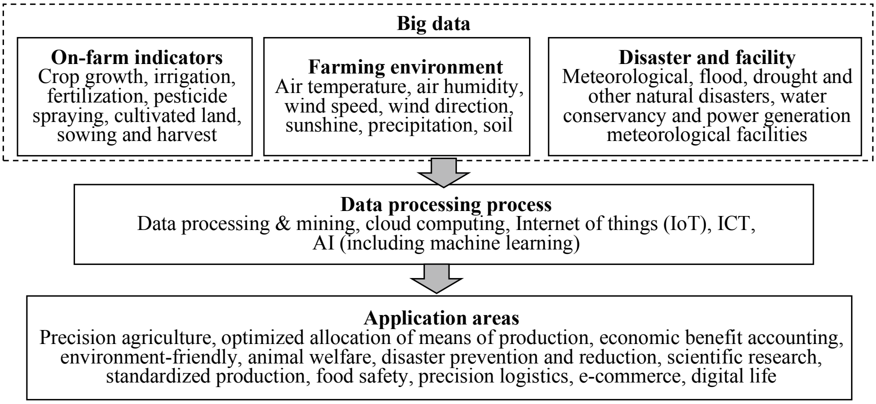

Fig. 1 Components and application fields of smart agriculture (Summarized and drawn by the authors)

(3) ICT: The general name for all communication equipment such as computers, network hardware, satellite system, and various services and application software for video conference, distance education, and so on. It provides great potential for better management of big data and efficiency improvement of agricultural production and business (Zhang et al., 2016). (4) Data mining: A process to determine the general and essential relationship between variables using statistical theories and methods through empirical analysis of large volumes of data (Xiang, 2019). (5) Cloud computing: A network formed by the interconnection of multiple computer terminals. Huge data computing tasks are decomposed into several small programs, processed and analyzed by different servers, and then fed back to users through the network (Yang et al., 2022).

2.2 Smart Agriculture Practices in China

2.2.1 Extension Rate Among Regions and Sectors

China's smart agriculture started in the 1980s. Although China's smart agriculture is backward compared with that of some leading countries, it is developing rapidly in recent years. Several new generation technologies such as IoT, sensor and remote monitoring, wireless transmission, big data and AI have been applied to agriculture. Through automation, digitalization, networking and intellectualization, smart agriculture has improved the agricultural management and production efficiency of China. According to the estimation of Qianzhan Industry Research Institute (QIRI),[2] the potential market size of China's smart agriculture has increased from US$13.7

[2] "Qianzhan" means "foresight" in Chinese. This listed institute was founded in 1998 at Tsinghua Campus, Beijing. It is committed to providing enterprises, governments, and research institutes

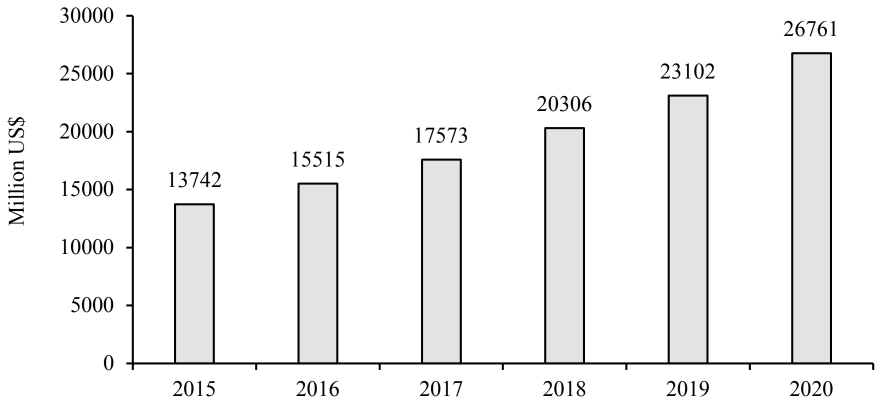

Fig. 2 Market size of smart agriculture in China from 2015 to 2020 (Reproduced from https://www.qianzhan.com/analyst/detail/220/190513-8c89e13f.html)

billion in 2015 to US$26.8 billion in 2020, representing an annual growth rate of 14.3% (Fig. 2). China's smart agriculture includes four typical application scenarios. From the market share released by the QIRI (2019), they are data platform services (40%), unmanned aerial vehicle (UAV) plant protection (35%), automatic agricultural machinery (10%) and fine breeding (15%). The 2015 and 2020 agricultural GDP of China were US$977.3 billion and US$1127.3 billion, respectively. Thus, in 5 years, the share of smart agriculture in China increased by one percent, from 1.4% to 2.4%. This indicates that China has a large potential for smart agriculture.

2.2.2 Smart Agriculture Industry Chain

China's smart agriculture has formed a relatively perfect industrial chain. The upstream chain consists of integrated circuits, satellite navigation systems, and sensors, whose components are manufactured mainly using nonferrous metals, monocrystalline silicon, and electronic ceramics. The midstream chain includes data platform, UAV plant protection, automatic machinery, and smart breeding, while the downstream chain involves the processing of plant and animal products (Fig. 3).

From Table 1, China's domestic enterprises provide the necessary products and technical support for the spread of smart agriculture in China in all sectors. Many of these enterprises are listed companies, such as CHC, Hi-Target, Hwali Create, SMIC, HIK Vision, and New Hope Group. While several of these enterprises were established around 2000, some such as COFCO Corporation, a time-honored state-owned enterprise group, were established in the 1940s, and others such as UML-Tech were new companies registered in the middle of the 2010s. The favorable policies of

with forward-looking advisory and solution reports in the fields of industrial application, planning, layout, upgrading and transformation, segmentation, and big data.

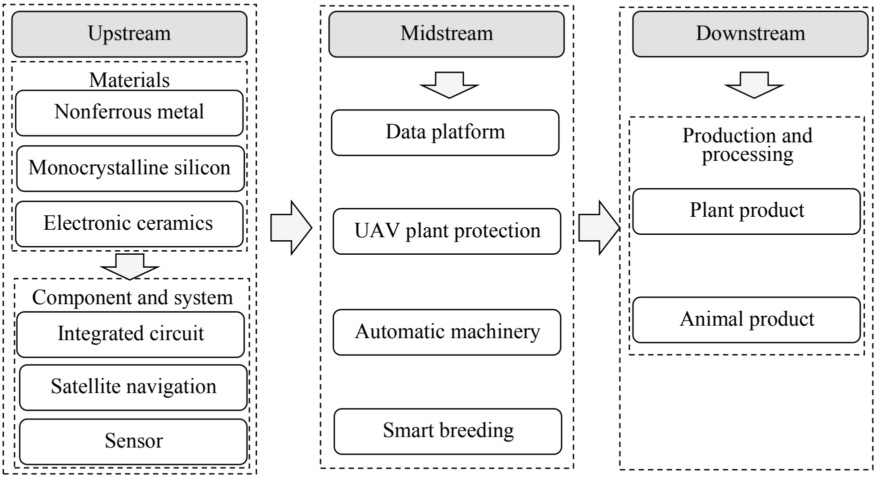

Fig. 3 Schematic diagram of China's smart agriculture industry chain (Reproduced from https://bg.qianzhan.com/trends/detail/506/211009-d9290910.html)

China prompted several traditional planting and breeding enterprises such as COFCO and Wens to adopt smart agriculture. In addition, many modern internet enterprises with smart technology have actively entered this field. For example, the internet giant NetEase started smart pig raising in 2009. It used modern technology to remotely monitor the physical condition, food intake, and excretion of pigs to provide them with a high-quality and comfortable living environment and produce delicious and safe pork (QIRI, 2021).

2.3 Case Study of the Smart Agriculture Model in Ruian County, Zhejiang Province

Located on the southeast coast, Zhejiang is one of the most economically developed provinces in China, with rural reform in a leading position. In January 2006, Zhejiang started a triune reform by integrating the farmers' cooperatives of agricultural production, supply and marketing, and credit access. In March 2006, China's first triune cooperative was established in Ruian County, southeastern Zhejiang. With hills and mountains accounting for 60.8% of the total area, Ruian is subject to frequent climatic disasters, complicated topography and soil types, and scattered individual small-scale family farms. Since 2020, Ruian has adopted the Modern Agriculture Platform (MAP) of the Syngenta Group,[3] to actively integrate smart technologies into the triune system (CPC committee & government of Ruian, 2021).

[3] Syngenta Group is a multinational state-owned enterprise established by China Sinochem Holdings Co., Ltd. on January 5, 2020. It is a global agricultural technology giant headquartered in Basel,

Table 1 Representative products suppliers of smart agriculture in China (Summarized by the authors, https://bg.qianzhan.com/trends/detail/506/211009-d9290910.html)

	Sector	Representative supplier (Year of establishment, headquarter location)
I	Satellite navigation	BdStar (2000, Beijing), CHC (2003, Shanghai), Hi-Target (1999, Guangzhou), Hwali Create (2001, Beijing)
	Integrated circuits	SMIC (2000, Shanghai), TSMC (1987, Taiwan), SK hynix (1987, Korea)
	Sensors	HIK Vision (2001, Hangzhou), Dali technology (2001, Hangzhou), Goertek (2001, Weifang)
	Nonferrous metal	Xinjiang Joinworld (1958, Urumqi), Wanfang aluminum (1996, Jiaozuo)
	Monocrystalline silicon	TJSemi (1988, Tianjin), Longi (2001, Xi'an), Jinglong (1996, Xingtai)
	Electronic ceramics	Kyocera (1959, Japan), CCTC (1970, Chaozhou)
II	Data platform	Haixinhuaxia (2008, Beijing), Aoko (2009, Beijing)
	UAV plant protection	DJI (2006, Shenzhen), XAG (2007, Guangzhou)
	Automatic machinery	UML-Tech (2014, Beijing), ComNav (2014, Shanghai)
	Smart breeding	NetEase (1997, Guangzhou), Tequ (1997, Chengdu), Wens (1983, Yunfu)
III	Plant product	COFCO Corporation (1949, Beijing)
	Animal product	Deep Agriculture AI (2015, Nanjing), New Hope Group (1982, Beijing & Chengdu)

Thus, Ruian has been able to overcome the constraints of natural conditions and achieve remarkable economic and social benefits. Using a cloud platform, MAP builds digital applications (APPs) for mobile terminals and personal computer (PC) to integrate agricultural production, management and governmental affairs. Thus, it establishes a comprehensive online service system covering subsidies and credit access, agricultural production, supply, and marketing, and the processes before, during, and after production. Using digital technologies such as remote sensing, big data, cloud computing, IoT, blockchain and the AI, this system could mainly built the four worry-free agricultural service scenarios of subsidy, loan, planting, and selling in Ruian (Fig. 4). MAP is designed to digitally promote the comprehensive upgrading of cooperative services and benefit the farmers through reduced costs and risk, and improved efficiency and profitability.

Within two years, the smart agriculture mode incorporated 1,094 cooperatives, 1,734 agricultural business entities, and 1,425 online farmer platforms. Using the whitelist system of credit authentication, it certified the credit identity of 1,425 farmers and granted 80.3 million yuan of loans. To support production, among 28

Switzerland, with operations in more than 100 countries around the world. Its main businesses include plant protection, seeds, crop nutrition, and smart agricultural technology.

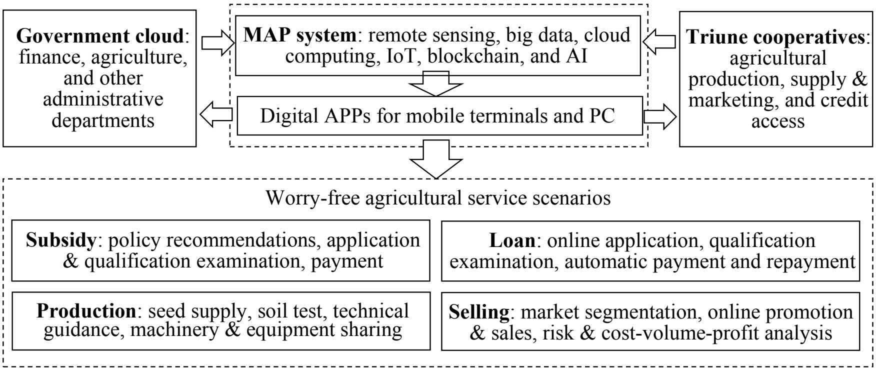

Fig. 4 Constitution of the smart agriculture system in Ruian, Zhejiang Province (Summarized and drawn by the authors)

agriculture-related services, it developed a smart early-warning system to realize real-time decision-making and action. It also established extensive cooperation in agricultural product supply, direct selling, and corresponding mechanisms for unsalable products with at least 15 e-commerce platforms, 45 farmers markets, and 196 public institution canteens (CAICT & CARD, 2021). For instance, using unified trademarks and packaging, the Meiyu vegetable cooperative created brand vegetables to enter the local high-end supermarkets and Hong Kong market, increasing their profits by four to five times. Furthermore, the introduction of robots reduced the production cost by US$1,200 per hectare (Li & Liu, 2021). In short, this case study showed that smart agriculture can play a significant role in the development of regional agriculture and the rural economy.

3 Promotion of Smart Agriculture

3.1 National Policies in China

In China, the CPC Central Committee and the State Council jointly issue their annual *Central No. 1 Document* specifying the key issues to be solved with priority every year. In 2012, the document proposed the promotion of precision agriculture technology. The following years saw the document specifying more relevant terms and preferential policies favoring the rapid extension of precision agriculture technology. In 2015, the document adopted "intelligent agriculture" with necessary technological breakthrough. In 2016, it proposed the vigorous promotion of information technologies such as internet plus, IoT, cloud computing, big data, and remote sensing. Since

2017, the document has been using the term of "smart agriculture",[4] regarding rural revitalization, rural e-commerce, and other post-2018 promotion measures[5] (Table 2).

In January 2019, the Ministry of Agriculture and Rural Affairs and the Office of the Central Network Security and Information Technology Commission jointly released the *Digital Agriculture and Rural Development Plan 2019–2025*. This plan defined the specific objectives and key tasks, and scheduled the smart transformation of agriculture and rural areas from the perspectives of resources, production and management, public service, and governance. In May 2019, the Central Committee of the CPC and the State Council issued the *Outline of Digital Village Development Strategy* proposing to complete rural digitalization by the middle of the century, specifying their phased goals and plans.

The central government's specific policies on the spread of smart agriculture must be implemented through the relevant ministries and commissions. The Ministry of Agriculture and Rural Affairs has a key role in promoting smart agriculture from the following aspects: (1) Implementing key projects: By September 2021, their targets include 9 provinces and 426 projects demonstrating IoT, 100 digital pilot projects, 210 digital demonstration bases, and 120,000 informatized machinery. (2) Special subsidies: The Guidance on Agricultural Machinery Purchase Subsidy 2021–2023 was issued jointly with the Ministry of Finance in March 2021. This increased the subsidy rate for some products to 35% and stipulated that the machinery excluded can be subsidized through special pilot or appraisals. A special project was set up to promote R&D, demonstrate and promote smart machinery, and form an innovative consortium of leading machinery enterprises. (3) Construction of informatization standards: A technical committee for agricultural informatization standardization established in 2016 included four working groups for big data, IoT, network information security, and e-commerce. A *standard system for agricultural informatization* (provisional) was formulated, and two standards, *the basic metadata of agricultural information and technical specification for agricultural data sharing*, were officially released. (4) Data sharing: Since 2016, big data and data sharing have been promoted in 21 province-level regions, with big data centers constructed for eight agricultural products such as rice, soybean, oil, and cotton. An online market information platform for staple agricultural products was established in 2017. This provided large amounts of authoritative, timely, and machine-readable data. (5) Talent training: Since 2015, 100 million farmers have been trained nationwide in smart phone application skills. Fourteen e-commerce courses have been held after 2018 covering a total of 1500 trainees (MARA, 2021a).

[4] Here, "intelligent agriculture" and "smart agricultural" are used to differentiate the two Chinese terms of "智能农业" and "智慧农业". The main difference is that "intelligent agriculture" emphasized the industrialization of agricultural production under relatively controllable environment and conditions (Yang, 2019, p. 11).

[5] The background is that the 19th CPC National Congress held in October 2017 put forward the goal of rural revitalization.

Table 2 Topic and contents relating to smart agriculture in the *Central No. 1 Document* jointly issued annually by the Central Committee of CPC and the State Council of China in January to February (Summarized by the authors)

Year	Topic of the No. 1 Document and contents relating to smart agriculture
2012	*Accelerating the innovation of agricultural science and technology to continuously enhance the supply capacity of agricultural products*: to accelerate research on cutting-edge technologies to achieve major independent innovation achievements in information communication and precision agriculture
2013	*Accelerating the development of modern agriculture and further enhancing the vitality of rural development*: to develop agricultural information services with emphasis on information collection, accurate operation, remote digitalization and visualization, meteorological prediction and forecasting, and disaster warning
2014	*Comprehensively deepening rural reforms and accelerating agricultural modernization*: to build an information and mechanization technology system focusing on the IoT and precision equipment, promote the R&D of new industrial especially facility agriculture and intensive processing
2015	*Strengthening reform and innovation to speed up the construction of agricultural modernization*: to make major breakthroughs in intelligent agriculture, agricultural machinery and equipment
2016	*Implementing the new development concept, speeding up agricultural modernization, and the building of all-round well-off society*: to implement key projects of intelligent agriculture; to promote smart meteorology and remote sensing; Internet plus; updating agriculture through Internet$^+$, IoT, cloud computing, big data and remote sensing
2017	*Deepening the agricultural supply-side structural reforms and accelerating the cultivation of new driving forces for agricultural and rural development*: to implement smart agricultural projects and promote the demonstration of the IoT and smart equipment; to promote smart meteorology and disaster monitoring
2018	*Implementing the rural revitalization strategy*: vigorously promote digital agriculture, implement smart agriculture, and promote IoT pilot demonstration and remote sensing technology applications
2019	*Giving priority to improving the work on agriculture, rural areas and farmers*: to foster a number of technological innovation forces, and promote independent innovation in smart agriculture
2020	*Promoting the key work in agriculture, rural areas and farmers to ensure the realization of all-round well-off society on schedule*: to build agricultural and rural big data center, promoting the application of IoT, big data, blockchain, AI, the 5G mobile communication network, and smart weather forecasting
2021	*Comprehensively promoting rural revitalization, accelerating agricultural and rural modernization*: to promote smart agriculture, establish agricultural and rural big data system, and deepen the integration with new generation IT
2022	*Key work of comprehensively promoting rural revitalization in 2022*: to support the construction of smart grain depots, R&D and application of high-end smart machinery, and develop smart environmental controlling

3.2 *Local Polies Promoting Smart Agricultural Technology*

Under unity arrangement of the national authority, local governments have a role to play in strategic guidance, rule formulation, policy support, standard construction and improvement in public services. Many province-level regions have issued plans, guidelines, opinions and schemes to set goals for smart agriculture promotion with different paths based on their respective endowment features (Table 3). These policies aimed to promote smart agriculture by activating the key issues of infrastructure, e-commerce and information services. Local governments are encouraging and guiding the inflow of funds, talents, technology and other elements from multiple market entities such as internet enterprises, farms, groups or individuals engaging in agricultural production and management. Thus, China is forming a mechanism incorporating government guidance and market entity coordination to accelerate the digitization, networking and intellectualization of agriculture. This is a mechanism guiding resources from cities and towns to rural areas, and from other industries to agriculture.

4 Perspective of Smart Agriculture in China

4.1 *Development with High Speed and Quality*

4.1.1 Promoting Continuously Enriched and Improved Policies

In China, the government provides strategic guidance, rule-making, and policy support considering the specific advantages and actual conditions of various regions. The central government issues increasing plans, guidelines, opinions, and schemes to the local governments and updates them to promote smart agriculture in terms of infrastructure, e-commerce, and information services. Through standard construction and public service improvement, the government guides and encourages multiple market entities to participate in and improve the evolving system of smart agriculture, which is closely integrating with rural vitalization and digitalization of the national economy. Furthermore, China has declared to achieve its carbon emission peak and neutralization goals by 2030 and 2060, respectively. On October 24, 2021, the State Council issued the country's action plan for carbon peak by 2030, which included a plan for agriculture in 10 key sectors to promote green and low-carbon growth. Smart agriculture provides a feasible path to change the traditional mode through digital transformation and dynamically obtain resource information, support intelligent, and accurate management. Thus, it supports the precise utilization of resources, improves production efficiency, and reduces carbon emission.

Table 3 Policies related to smart agriculture in some Chinese province-level regions (Summarized by the authors)

Region	Document and main contents concerning smart agriculture
Shandong	*Digital development plan (2018–2022)* (Issued in Feb. 2019): Build a provincial smart agriculture cloud platform, a number of smart agriculture parks and demonstration bases, information centers, new ecological agriculture models integrating smart planting, breeding and processing
Heilongjiang	*Digital development plan (2019–2022)* (Issued in July 2019): Construct sky-land integrated information remote sensing and monitoring network. Accelerate the digital transformation standardization for characteristic industries of grain, oil, fruits, vegetables, dairy, forest frogs, and black pigs. Build a number of smart agriculture demonstration areas and promote the application of big data
Chongqing	*Action plan of smart agriculture development (Trial)* (Issued in Nov. 2019): Develop smart agricultural application standards and specifications, low-cost technologies and equipment, standardized data collection and AI data models, and 200 demonstration bases by 2022
Yunnan	*Implementation Opinions on accelerating the construction of digital countryside* (Issued in April 2020): Promote the dynamic monitoring of permanent basic farmland using remote sensing, the application of cloud computing, big data, IoT and AI in agriculture. Establish an intelligent supply chain for agricultural products
Jiangxi	*Three-year action plan for digital economy development (2020–2022)* (Issued in April 2020): Promote digital projects in field planting, horticultural crops, livestock and poultry breeding and aquaculture. build a smart agricultural service system and 200 Agricultural IoT demonstration bases by 2022
Henan	*Opinions on accelerating agricultural informatization and digital village construction* (Issued in April 2020): Build IoT demonstration bases for field crops such as wheat, corn, rice and peanut, build smart modes of facility agriculture, forestry and fruiter, improve information service system of animal husbandry, promote smart fishery and seeding, and improve the level of intelligence, automation and refinement of agricultural processing
Fujian	*Implementation plan of "Internet plus" agricultural products coming out of villages* (Issued in June 2020): 2020–2022, build more than 700 smart agricultural parks and IoT application bases. Improve the coverage of rural broadband, optical fiber, mobile network, satellite network to meet the needs of agricultural network
Liaoning	*Development planning of digital village* (Issued in Aug. 2020): Promote the dynamic monitoring of permanent basic farmland using remote sensing, high-resolution earth observation system in agriculture, smart agriculture center, agricultural and rural big data system

(continued)

Table 3 (continued)

Region	Document and main contents concerning smart agriculture
Hebei	*Special action plan for smart agriculture demonstration construction (2020–2025)* (Issued in Oct. 2020): By 2020, 100 bases and improve the ratio of agricultural IoT over 18%; large-scale smart facility planting, livestock, poultry, and aquaculture over 60%. By 2025, 100 large-scale smart agriculture demonstration bases and the intelligent rate of national and provincial modern agricultural parks reach 100%
Jiangsu	*Opinions on promoting the construction of digital countryside with high quality* (Issued in Jan. 2021): Build the provincial agricultural IoT service platform, 100 provincial digital agricultural in 3–5 years. Strengthen the R&D and application of key digital agricultural technology and equipment
Shanghai	*Action plan for promoting high-quality agricultural development (2021–2025)* (Issued in Jan. 2021): Build smart agricultural production bases, 10 ha unmanned farms, smart vegetable (fruit) gardens. Construct the digital agricultural information platform, improve the innovation ability of modern seed industry
Beijing	*Plan on promoting rural revitalization and accelerating agricultural-rural modernization* (Issued in Mar. 2021): Build smart agricultural innovation workshops, 5 national and 15 municipal modern agricultural parks, and 100 agricultural science and technology demonstration bases to improve agricultural digitization
Jilin	*The 14th five-year plan for the development of digital agriculture (2021–2025)* (Issued in May 2021): By 2025, build digital agriculture big data centers and cloud platforms at provincial, prefecture and county levels, to cover 80% of corn, rice, pigs and beef cattle farmers; build variety-specific big data service platform in 4 characteristic industrial fields: sika deer, ginseng, edible fungi and blueberry, covering over 90% farmers
Tianjin	*The 14th five-year plan for promoting agricultural and rural modernization* (Issued in June, 2021): Promote the construction of Tianjin Smart Agriculture Institute, the R&D in agricultural remote sensing, UAV, new sensors, big data, blockchain and robot, accelerate the industrialization of achievements in key fields such as field crops, protected horticulture, livestock and poultry breeding and aquaculture

4.1.2 Rapidly Developing Rural Telecommunication to Consolidates the Foundation

With the fast and steady deployment of infrastructure, China has roughly realized full internet coverage of its rural areas. Since 2015, the Ministry of Industry and Information Technology and Ministry of Finance have jointly implemented six universal telecommunication service pilot projects supporting the construction of more than 50,000 4G base stations with optical fiber in 130,000 villages, with about 1/3 of the facilities deployed in rural areas. By May 2021, more than 99% of the villages had access to optical fiber or 4G network, thus giving China the world's largest optical fiber and 4G network. During this period, the construction speed and scale of China's 5G network ranked first in the world, with an accelerating spread to rural areas. By the end of 2020, China had at least 718,000 5G base stations and over 200 million 5G terminals (CAICT & CARD, 2021). The rapid spread of new generation high-speed networks to rural areas could thus lay the foundation for smart agriculture in terms of hardware facilities, public interest, and skills.

4.1.3 Rapidly Increasing Capacity of New Generation Information Technology

With agricultural modernization and informatization becoming a key topic in the *Central No. 1 Document* after 2015, an increasing number of enterprises and scientific institutions have been investing in smart agriculture, significantly accelerating the transformation of achievements. According to the China National Intellectual Property Administration (https://pss-system.cnipa.gov.cn), 134 patents related to smart agriculture, internet agriculture, and agricultural informatization have been registered by August 2021. The World Intellectual Property Organization (WIPO) reported that 2064 patent applications related to smart agriculture were registered in China by August 2021; this was ranked first in the world. The number of patents in the major sectors were as follows: management and control (661), growth and breeding (580), monitoring and detection (304), information collection (276), picking and processing (64), e-commerce logistics (45), agricultural decision-making (35), and social services (26).

4.2 Constraints and Bottlenecks of Smart Agriculture

4.2.1 Need to Improve Sustainability and Independence of Most Smart Agricultural Projects

The R&D of smart agriculture takes a long period because it must cross several disciplines such as digital technology, agronomy, meteorology, and geography. Moreover, smart agriculture projects require continuous investment and face relatively greater technical and investment risks, making them less attractive to social funds. According to Cao et al. (2021), almost 50% of smart agriculture enterprises found the start-up construction costs too high, while 33% found the maintenance costs even higher, making it difficult for them to even recover their original investment. Furthermore, although the number of patent applications related to smart agriculture in China was the highest in the world, China faces a low rate of converting smart agriculture research achievements into field application. Some studies pursue the academic novelty and cutting-edge nature of the study or are guided by the criteria of article publication and project assessment, and do not fully consider the practical needs and acceptability. Moreover, China lacks independent innovation in key technologies such as crop growth modeling and production control software. Smart planting platforms, both in the field and facility of agriculture, are still in the early stages of commercialization. Several models and software were imported from institutions in the Netherlands, the US, Israel, and other countries (CAICT & CARD, 2021). Most smart agriculture pilot projects focus on the transmission and display of information, and do not deeply integrate with agriculture or have the means to solve the practical problems (Song, 2020).

4.2.2 Insufficient and Unbalanced Fiscal Investment

By having greater social than economic benefits for a long period, smart agriculture in China has made it obligatory for the government to invest and promote it. However, because of limited budgets and awareness, the government at all levels have relatively insufficient funds for investment in smart agriculture. According to the information center of the Ministry of Agriculture and Rural Affairs, the county-level[6] financial investment in agricultural and rural informatization in 2020 accounted for only 1.4% of the national financial expenditure on agriculture, forestry, and water affairs. Of the 2703 county-level administrative regions sampled for monitoring and evaluation, 535 regions, accounting for 20.2% of the sample, did not have financial investment for agricultural and rural informatization; 22% of the regions still have neither administrative department nor public institution, such as an information center to undertake information work. This indicates the urgent need to improve the institutional and personnel capacity of smart agriculture (MARA, 2021b). In addition, the funds earmarked by the government for smart agriculture tend to support platform construction, especially those with large visual screens. According to the Chinese government's procurement website, of the 709 local government procurements relating to smart agriculture during the period 2014–2020, 268 were used for platform construction. These platforms have highly similar functions and poorly meet the needs of smart agriculture (CAICT & CARD, 2021).

4.2.3 Farmers Lack the Foundation to Extend Smart Agriculture

At present, owing to the low profitability of agriculture, most young and middle-aged people seek employment in other industries. Thus, the elderly and women constitute the main labor force of agriculture and the demand for new agricultural technologies is insufficient. The multiple cropping index of cultivated land has decreased and many farmlands have been abandoned. Rural land transfer lacks orderly guidance, and this affects the scale enlargement of agricultural management. More than 98% of agricultural business entities are household farms; these account for 90% of the

[6] China has five administrative divisions, central, provincial, municipal, county, and township, of which the county and township are generally classified as rural areas.

agricultural labor and 70% of the cultivated land (CAICT & CARD, 2021). The small scale of household farms makes them less profitable and incapable to adopt new information technologies. Since 2016, the average net profit per unit area of the three major grain crops, wheat, rice, and corn, has remained negative when labor cost is included. In 2019, the average output per labor was equivalent to only 4% in Israel, 5% in the US, 15% in the EU, and 17% in Japan (Zhao et al., 2021). The high costs are generally not affordable for most farmers, and this, along with the technical thresholds, constrains the promotion of smart agriculture. Therefore, smart agriculture is generally applied to some high-value cash crops, with only a few economically strong enterprises exploring its small-scale application.

4.2.4 Smart Agricultural Talent-Training System yet to be Established

The *Outline of digital rural development strategy* and the *Digital agriculture rural development plan (2019–2025)* have a series of arrangements to train digital agricultural talent. Since 2018, the Ministry of Education has approved the proposal of more than 10 agricultural universities to set up undergraduate majors in areas such as AI, data science, and big data technology and the establishment of 15 majors in smart agriculture, 6 majors in agricultural intelligent equipment engineering, and 2 majors in smart animal husbandry science and engineering. However, this is insufficient to meet the social demand for professional talent, and most studies are still in the stage of exploration and theoretical research. In a survey by Cao et al. (2021), nearly 60% of the business entities estimated that the largest obstacle to agricultural informatization as shortage of talent. More than 80% of the enterprises have a demand gap for smart agricultural talent, of which the demand for technical talent is the largest, accounting for 59.3%. Among them, 62.9% found it difficult to recruit excellent talent, while 14.8% found this very difficult. In addition, the information technology skills training for farmers and new agricultural business entities is insufficient, with 40% of business entities saying that they lacked professional skills guidance. Thus, China's interdisciplinary smart agricultural talent training base and academic platform are yet to be fully established, implying a great demand for smart agricultural application and management talent.

4.3 Suggestions to Accelerate the Promotion of Smart Agriculture in China

4.3.1 Improve the Quality of General Development Plans

At present, the governments at all levels continue to issue plans for smart agriculture promotion, but there are problems of unclear objectives and measures, and convergence of policies in different regions (Zhao, 2020). (1) National plans should focus on financial support and R&D in key technologies, clarify the objectives of smart agriculture at each stage, such as every five years, and decompose the responsibilities to different departments and regions (Cao et al., 2021). (2) Local plans should formulate schemes in combination with the national arrangements and regional resource endowment. (3) The plans should gradually guide, considering the basic position of the market in resource allocation and the leading role of enterprises in technical R&D and promotion (Song, 2020). (4) The plans should be formulated in combination with the goals of carbon emission peaking and neutralization, with focus on smart technologies promoting energy conservation and green development in agriculture and rural areas. (5) Specific paths should be planned for different entities with focus on promoting the effective connection between small farms and modern agriculture, optimizing the scales to improve the managerial capacity of family farms, supporting cooperatives, and leading enterprises along with other large-scale entities to build modern agricultural parks (Zhao et al., 2021).

4.3.2 Increase the Amount and Efficiency of Fiscal Support

(1) Provide policy subsidies to enterprises that produce, manufacture, promote, and apply key smart agriculture technologies and products under the subsidy policy for purchase of agricultural machinery. (2) Strengthen the guiding role of finance, taxation, and insurance to attract private capital to smart agriculture infrastructure construction through loan interest discounts, finance guarantees, and other policies (Zhao, 2020). (3) Increase the support for projects set up jointly by production, teaching, and research institutions to ensure that financial funds are used more efficiently for scientific research and agricultural production through direct connection between the market, enterprises, and farmers.

4.3.3 Identify the Key Technologies and Promote Independent Research

Key technologies have the following aspects. (1) Smart service: new generation agricultural visual human-computer interaction and adaptive agricultural cloud service. (2) Smart decision-making: Agricultural big data and computational intelligence, support decision-making system, and knowledge model and algorithm. (3) Smart control: High-end plant protection UAV, smart equipment for harmless treatment of dead livestock and poultry, agricultural robot, postpartum treatment, and circulation equipment control of agricultural products. (4) Information perception: Agricultural product quality information perception, environmental information perception, agricultural machinery sensor, and life information perception (Zhao et al., 2021).

The promotion measures could be as follow: (1) Update the laws, regulations and policies related to investment, credit access, taxation and intellectual property rights protection. (2) Rely on the national key R&D program of China,[7] and the innovation fund for technology-based firms[8] to guide enterprises to participate in the R&D of smart agriculture. (3) Integrate the market mechanism and specific projects in R&D, demonstrate and apply key smart technologies and products, encourage service-oriented enterprises to engage in agricultural businesses in market report and digital finance forms, and guide the smart transformation of agricultural enterprises (CAICT & CARD, 2021).

4.3.4 Improve the Education, Training and Technology Promotion System

(1) Strengthen the information technology training for farmers: Use highly popularized information means such as smart phone Apps, social network sites (SNS), and webcasts to improve farmers' cognition and interest in smart technology, and supplement this through offline training activities to remove the constraints of conventional production (Wang, 2020). (2) Create a multiple-subject cultivation system: Following the government or industry association initiatives, collaborate with the education, research, and technology institutes in promoting smart skills in rural areas by providing platforms, personnel, and resources. (3) Cultivate skills in school education: Innovate the curriculum, teaching material, and methods of courses to ensure that students obtain digital skills. Furthermore, promote the vocational education system by increasing the enrollment of students and create smart technology-related courses to meet the needs of agricultural production and management (CAICT & CARD, 2021). (4) Create conditions for all types of talents to participate in smart agriculture: Establish cooperatives, information platforms, and other institutions and supplement them through preferential measures, such as low-interest loans and tax reliefs to facilitate entrepreneurship and social services, and popularize smart technologies in agriculture and rural areas (Song, 2020).

[7] This was established in 2015 and managed by the Ministry of Science and Technology to fund major studies of social welfare as well as the development of key technologies and products relating to the core industrial competitiveness, the overall independent innovation ability and national security.

[8] This was established with the approval of the State Council in 1999 and managed by the Ministry of Science and Technology under the supervision of the Ministry of Finance. It gives full play to the guiding role of financial funds and channel social funds and other innovative resources to support the development of science and technology-based small and medium-sized enterprises, through free subsidies, loan discount, and capital investment (http://innofund.chinatorch.gov.cn/english2/index.shtml).

5 Conclusion

The government of China has issued a series of policies at the national and regional levels for the promotion of high-quality agricultural development, rural revitalization, and green and low-carbon development and to accelerate the spread of smart agriculture, which has attracted the attention of many scholars. In recent years, China is witnessing a rapid increase in its smart agriculture market scale, technology, R&D, and promotion, and the industrial chain has begun to take shape. With the support of consistently improving policies, popularization of the rural telecommunications industry, and the continuous enhancement of information technology and R&D capacity, the overall perspective of smart agriculture in China appears optimistic. A case study of the practices in Ruian County of Zhejiang Province has confirmed this. However, smart agriculture confronts constraints from poor project independence and sustainability, unbalanced and inefficient financial support, weak economic and knowledge base of farmers, and a lagged talent training system. From academic findings, smart agriculture in China can be further promoted through better overall planning, increased efficiency of financial investment and R&D of independent technology, and an improved training and technology promotion system.

China's mode to promote smart agriculture depends on the overwhelming ratio of small-scale farms, relying on government policies and investment to increase the participation of large enterprises. It also focuses on the digital village, carbon peak and neutralization to gradually improve the farmers' professional quality, managerial scale and the utilization efficiency of agricultural resources and rural ecological environment. The huge agricultural and rural economy of China and its ever-changing production and R&D practices provide a broad space for further qualitative and quantitative studies, summarizing the modes and effect, popularizing the experience, and deepening the follow-up analyses of smart agriculture.

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