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Research on Strategies for Empowering Rural Revitalization through Digital Farming Supported by AI Technology

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Abstract: In the context of rural revitalization, traditional agricultural production models face shortcomings such as low ecological carrying capacity, poor space utilization efficiency, weak industrial coupling, inadequate environmental friendliness, and limited sustainability. This paper analyzes and studies the role of digital farming in empowering rural revitalization, exploring the application of AI technology in digital farming space production, management, and ecological governance. Based on an analysis of issues related to traditional agricultural production space, industrial ecological chains, and urban-rural spatial coupling, it proposes a design scheme for a digital farming environment based on AI technology. The aim is to provide theoretical support and practical references for upgrading rural industrial ecology, improving the quality and efficiency of the agricultural economy, and promoting the integrated development of urban and rural spaces.

Keywords: AI technology; Digital farming; Rural revitalization; Strategy research

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1. Research background

The overall approach and guideline for addressing issues related to agriculture, rural areas, and rural people in the new era is the rural revitalization strategy. Its essence lies in achieving the revitalization of industry, talent, ecology, organization, and culture at the rural level, to realize the vision of strong agriculture, beautiful rural areas, and prosperous farmers [1]. As the foundation and fundamental aspect of rural economic development, the quality of agricultural development is directly related to the progress of rural revitalization. However, China's current agricultural development level is low, with many shortcomings and numerous problems. Extensive agricultural farming methods, long-term reliance on empirical approaches and experiences in agricultural activities, and low agricultural production efficiency are among these issues. Data from the National Bureau of Statistics in 2023 shows that China's agricultural labor productivity is only one-eighth of that of the secondary industry and approximately one-quarter of that of the tertiary industry. High pesticide and fertilizer usage has led to increased agricultural planting costs, agricultural land degradation, reduced soil fertility, and environmental issues such as soil and water pollution. In 2022, China's fertilizer application rate per unit of cultivated land was still nearly 20% higher than the global average. The decentralized management approach of small farmers is incompatible with the development requirements of modern agriculture, such as scale and standardization, and agriculture's ability to resist risks is relatively poor. These factors have become shortcomings on the path to rural revitalization.

In this broader context, the integration of digital technology and agriculture has emerged as a key to overcoming agricultural bottlenecks, leading to a new form of agriculture known as "digital agriculture." Digitalization and intelligence are transforming various stages of agricultural production, including pre-production, mid-production, and post-production, as well as agricultural management and rural administration. This shift is moving towards precision farming, efficient management, and green development. Advances in artificial intelligence (AI) technology provide support for the further development of digital agriculture. Compared to traditional digital technologies, AI technology offers autonomous analysis and dynamic decision-making capabilities, better addressing various situations that arise during agricultural production [2]. For instance, it can establish crop growth models based on soil and meteorological data, providing a scientific basis for optimizing planting schemes. Image recognition technology can quickly identify crop pests and diseases and develop control plans. The use of autonomous farming machinery reduces human labor input and improves operational efficiency.

From a policy perspective, the central government's No. 1 documents in the past three years have consistently focused on the digital development process in the agricultural sector. In particular, the "Digital Rural Development Action Plan (2022–2025)" issued in 2023 clearly states the need to promote deep integration between AI and other technologies and agricultural production, providing policy support for related practical work [3]. In terms of specific practices, regions such as the AI+Wheat Field Base in Zhoukou, Henan Province, and the Smart Agriculture Demonstration Zone in Zhejiang Province have taken the lead in exploring technological applications. As mentioned by the Department of Science and Technology Education of the Ministry of Agriculture and Rural Affairs in 2022, the Zhoukou base in Henan Province achieved an average yield increase of 15% per mu and water savings of 30% through intelligent detection and precise implementation.

However, the promotion and application of AI technology in the agricultural sector still face many practical obstacles. On the one hand, the purchase and maintenance costs of technical equipment are relatively high, making it difficult for most small farmers to afford. Additionally, farmers' acceptance and operational capabilities of digital technology are limited, which has slowed down the progress of technology promotion to some extent. On the other hand, agricultural resource conditions vary across different regions, and highly versatile technical solutions often do not match the actual situations in various locations, leading to a phenomenon of "not suitable for local conditions." Furthermore, issues such as the fragmentation of agricultural data resources and the incomplete data sharing mechanism have also significantly restricted the application of AI technology. The existence of these problems not only prevents the full potential of AI technology from being realized but also limits the role of digital farming in promoting rural revitalization.

2. Analysis of deep-seated problems in traditional farming models

2.1. Low production efficiency

Traditional farming methods mostly rely on manual labor and animal power to complete various farming tasks, resulting in high labor intensity and low production efficiency. From sowing, fertilizing, irrigation to harvesting, each step requires a significant amount of manpower and time, making it difficult to achieve the scale and intensification required for modern agricultural production. For example, in large-scale farmland irrigation, traditional flood irrigation not only causes great waste of water resources but also has low irrigation efficiency, requiring a large amount of manpower for field management, resulting in long irrigation times and affecting the normal growth of crops. Moreover, under traditional farming methods, farmers lack scientific planting management knowledge and technology, and most of them rely on experience for planting, which cannot achieve optimal growth conditions for crops, thus unable to increase crop yield and quality [4].

2.2. Unreasonable resource utilization

Under traditional farming methods, the utilization of water, land, and fertilizer resources is very unreasonable. In water resource utilization, as mentioned earlier, flood irrigation wastes a lot of water resources and can cause soil compaction and even salinization, which can affect soil quality and planting. In terms of land use, due to the lack of scientific planning, the land is fragmented, which is not conducive to scale and mechanization, so the land is not well utilized. Regarding fertilizers, farmers often over-fertilize, which not only increases costs but also causes damage to soil quality and eutrophication of water sources, which is not conducive to the balance of agricultural ecosystems.

2.3. Market information asymmetry

Under traditional farming models, farmers have limited sources of market information, and information transmission is slow and inaccurate. There is information asymmetry in the market, and farmers cannot know market demand and price trends in time. Therefore, they often have to plant based on the market situation of the previous year, which can easily lead to supply and demand imbalances. When the price of a certain agricultural product rises in the market, farmers will flock to plant this agricultural product. In the next year, this agricultural product will be oversupplied, prices will fall, and farmers' income will decrease. Due to information asymmetry, farmers are always at a disadvantage when selling agricultural products and cannot obtain fair and reasonable prices, which can dampen farmers' enthusiasm for production.

2.4. Poor risk resistance

Traditional agricultural farming methods rely heavily on natural conditions and market environments, and their ability to resist risks is weak. Natural disasters such as droughts, floods, typhoons, and pests can cause significant damage to crops, and farmers do not have sufficient measures to resist these disasters. The agricultural product market often experiences price fluctuations, and farmers' market forecasting and risk prevention abilities are weak. Once agricultural product prices fall, farmers' incomes will drop sharply, and they may even incur losses. Under traditional farming models, the agricultural chain is too short, and the added value of agricultural products is too low, resulting in few sources of income for farmers, which further reduces their ability to resist risks.

2.5. Lack of sustainable development capabilities

The traditional farming model relies heavily on various chemicals such as fertilizers and pesticides during its development. Long-term and excessive use of these chemicals not only depletes the soil, damages the ecological environment, but also deprives agriculture of its vitality for sustained development [5]. Excessive fertilizer use gradually reduces the organic matter content in the soil, causing qualitative changes and significantly decreasing soil fertility. To maintain crop yields, farmers need to continuously apply more fertilizer, creating a vicious cycle that may lead to diminished returns from the land in the future. Harmful pesticides in fertilizers can also cause significant pollution to food. Overuse of pesticides not only leads to excessive pesticide residues in agricultural products, which can endanger people's health, but also kills beneficial insects and microorganisms in the soil, affecting the agricultural ecosystem. In the traditional farming model, agricultural waste such as straw and animal manure is not effectively managed, resulting in resource waste and environmental pollution.

3. Digital farming empowerment strategies based on AI technology

3.1. Promoting intelligent innovation in agricultural production

Increase investment in research and development of agricultural AI technology, actively promoting collaboration between research institutes, universities, and agricultural enterprises to create an industry-academia-research collaborative innovation system. Jointly tackle core technological bottlenecks in agricultural AI, such as crop growth modeling and intelligent pest and disease identification algorithms, to enhance the self-controllability of China's agricultural AI technology. In the technology promotion phase, rely on agricultural technology parks, modern agricultural demonstration bases, and other platforms to conduct multi-level and diverse technical training activities, including online courses and offline practical exercises. Encourage farmers to adopt intelligent agricultural tools such as smart farming equipment, IoT monitoring systems, and agricultural production management software, promoting the transformation of agricultural production methods towards intelligence, automation, and precision, achieving efficient resource utilization and improved production efficiency [6].

3.2. Building an integrated platform for agricultural big data

Integrate multi-source heterogeneous information such as agricultural production data, market circulation data, meteorological and environmental data, and soil and geographic data, to create a fully functional agricultural big data platform [7]. Utilize advanced data analysis techniques such as machine learning and deep learning to conduct in-depth analysis of large amounts of data, providing a basis for agricultural production decision-making. Use historical planting data and market price information to advise farmers on suitable crops to plant. Determine the most suitable planting time based on weather forecasts and crop growth patterns. Predict agricultural product price trends based on market price fluctuation models. For example, use the big data platform to establish a traceability system for agricultural product quality and safety, strengthen dynamic management of agricultural resources, and enhance agricultural disaster warning and response systems, improving the scientific and precise level of agricultural production management [8].

3.3. Developing a full industry chain ecology for smart agriculture

Driven by digital farming as the core, we will extend the agricultural industry chain upstream and downstream, integrating related industries such as agricultural product processing, cold chain logistics, and e-commerce to build a smart agriculture ecosystem [9]. With the help of AI technology, various parts of the industry chain can achieve connectivity and collaborative operation. By forming a data sharing mechanism, information islands can be broken through. In the agricultural product processing link, machine vision technology is used to detect product quality, relying on intelligent control systems to improve technological processes, thereby enhancing product qualification rates and production efficiency. In the logistics and transportation link, relying on an AI algorithm-based smart scheduling system, delivery routes can be planned in real-time based on factors such as traffic conditions and cargo attributes, thereby reducing logistics costs. In the sales link, AI marketing techniques are employed to analyze consumer behavior and preferences, implement precision marketing, expand sales channels through e-commerce platforms, and improve agricultural product market share and brand influence.

3.4. Shaping a high-quality new agricultural talent team

We will improve the vocational education and training system for farmers, aiming to cultivate new professional farmers who meet the development needs of digital farming. We will create multi-level and diversified training models. From the perspective of curriculum design, relevant courses such as agricultural AI technology application, agricultural big data analytics, and smart agriculture operations can be offered, with a focus on combining theoretical learning with hands-on practice. Farmers will be actively encouraged to participate in agricultural vocational skill training programs, and vocational skill qualification exams will be used to strengthen farmers' professional skill quality. Additionally, an agricultural science and technology special envoy system can be established, allowing scholars and experts from universities and research institutions to go to the front lines of rural areas to teach farmers technology, provide advice, and optimize farmers' digital technology application skills through the "teaching, helping, and leading" format, providing strong talent support for the development of digital farming [10].

3.5. Improving the policy guarantee mechanism for digital farming

The government should play a guiding role and formulate a series of policies to support the development of digital farming. In terms of industrial policies, measures should be introduced to encourage agricultural enterprises to apply AI technology and create smart agriculture. In terms of fiscal policies, funding should be increased for agricultural AI technology research and development and the creation of demonstration projects. A special fund for digital farming development should be established. At the level of tax policies, tax reductions and exemptions should be provided for enterprises engaged in agricultural AI technology research and development and smart agricultural production. Additionally, the relevant information infrastructure in rural areas should be strengthened, enhancing the quality of rural network coverage and broadband, and improving the hard conditions for the digital transformation of agricultural production. This will provide better policies and facilities for the development of digital farming [11].

4. Conclusion and outlook

4.1. Research conclusion

The tight integration of AI technology with digital farming has opened up new paths to solve the dilemmas of traditional agricultural development. Core application scenarios such as intelligent sensing and monitoring, precise planting decision-making, and intelligent pest control have enabled AI technology to redistribute agricultural production factors, effectively improving resource utilization. In smart agriculture demonstration zones, precise irrigation relying on AI technology can reduce water consumption by 30%. AI-assisted decision-making models can increase crop yields per unit of land by 25% to 40%. The agricultural product quality tracing system has also enhanced additional market earnings by more than 20%, all indicating the significant advantages of digital farming in improving production efficiency and enhancing industrial competitiveness.

However, the large-scale application of AI technology in agriculture still faces multiple obstacles. Poor infrastructure facilities lead to constraints in data transmission and equipment operation. Less than one-fifth of rural areas have 5G network coverage, which greatly affects the real-time communication and interaction of intelligent devices. The shortage of compound talents has become a technical challenge. Less than 80% of grassroots agricultural technicians have a good grasp of AI technology, and only more than 20% of elderly farmers are proficient in digital operations. The lack of complete funding methods has slowed down technology research and equipment improvement, and agricultural AI research and development operate at about one-quarter of the intensity of the industrial sector. Due to the absence of standard technical criteria, there are significant difficulties in interconnecting systems between different manufacturers, and data exchange between different manufacturers accounts for less than one-third of the total. Risks of information leakage and ethical loopholes in algorithm rules caused by legal and regulatory gaps urgently need to be resolved through multi-party collaboration.

4.2. Development outlook

The upgrading and replacement of AI technology will promote digital farming to a new stage. After the combination of cutting-edge technologies such as edge computing and quantum computing with agriculture, the intelligence level of agricultural production will move from partial to holistic. By around 2030, the global agricultural robot market value is estimated to exceed $50 billion. Smart agricultural machinery and equipment will be widely used in the entire agricultural production process, including farming, management, and harvesting. Furthermore, the crossover integration of AI with biotechnology and new energy technology will give birth to emerging formats such as smart seed breeding and energy agriculture, thus changing the agricultural industry structure.

The development of digital farming will not only bring fundamental changes to agricultural production methods but also drive the intelligent upgrading of the entire agricultural industry chain. From data collection in fields to agricultural product processing and intelligent e-commerce marketing, AI technology is expected to tightly connect various parts of the industry chain and achieve coordinated development, creating more than tens of millions of new job opportunities. This technological revolution will provide sustainable momentum for rural development, promote rural economic prosperity and social stability, and finally achieve the strategic goals of agricultural modernization and urban-rural integration.

Disclosure statement

The authors declare no conflict of interest.

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