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Research on the Development Path of Precision Agriculture Based on Big Data Application

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Abstract: With the continuous advancement of big data technology, its application in precision agriculture is becoming more and more extensive, which provides a new path for agricultural modernization. Based on the background of big data technology, this paper discusses the development path of precision agriculture. The research shows that the application of big data technology in precision agriculture is mainly reflected in crop growth monitoring and prediction, soil fertility assessment and regulation, water resources management and optimization, agricultural product traceability and origin tracing, and agricultural product supply chain management and risk control. However, the application of big data technology in the agricultural field still encounters numerous challenges, such as data collection and processing, data analysis and application, and privacy protection and security. To this end, this paper puts forward countermeasures, including strengthening infrastructure construction and establishing data sharing and management mechanisms.

Keywords: Big data; Precision agriculture; Development path

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1. Overview of the application of big data in precision agriculture in the Zhejiang Province of China

1.1. Big data infrastructure construction

Through the construction of the smart agriculture cloud platform and rural brain, Zhejiang Province has realized the efficient integration and application of agricultural data. The smart agriculture cloud platform integrates agriculture-related resources at all levels of provinces, cities and counties [1], forming a framework of “one platform, one center, and N applications,” covering data in multiple fields such as agricultural industry, Internet of Things, plant protection, agricultural machinery, and animal husbandry. In addition, the “11153” core framework has been built by the Rural Brain, which has achieved full integration at the provincial, municipal, and county levels, with an average daily visit of more than 1.2 million times.

Focusing on agricultural intelligence, rural intelligent governance [2], and farmers’ prosperity, we use digital technology to integrate computing power, data, algorithms, models, intelligent modules and other resources, build one warehouse, one map, one code, five libraries, three capabilities and 16 intelligent series of multi-cross application scenarios, and collect 1.6 billion pieces of data on agriculture, rural economies, and rural areas, which has effectively boosted the scientific decision-making [3], precise governance, and efficient service of agricultural and rural departments at all levels.

1.2. Precision agricultural production driven by big data

Through the combination of big data and Internet of Things technology, Zhejiang Province has promoted the wide application of precision agriculture (**Figure 1**) [4]. For example, in the "Tian Cube" Future Farm in Linping District, real-time field data is collected through intelligent equipment such as water quality sensors, insect monitors, and weather stations to provide accurate decision-making support for agricultural production. In addition, Zhejiang has also promoted new planting technologies such as "aeroponics," and used big data analysis to optimize the growth environment of fruits and vegetables, which significantly improved yield and resource utilization efficiency.

In terms of grain output, from 6.21 million tons in 2022 to 6.502 million tons in 2024, the growth has achieved a qualitative leap.

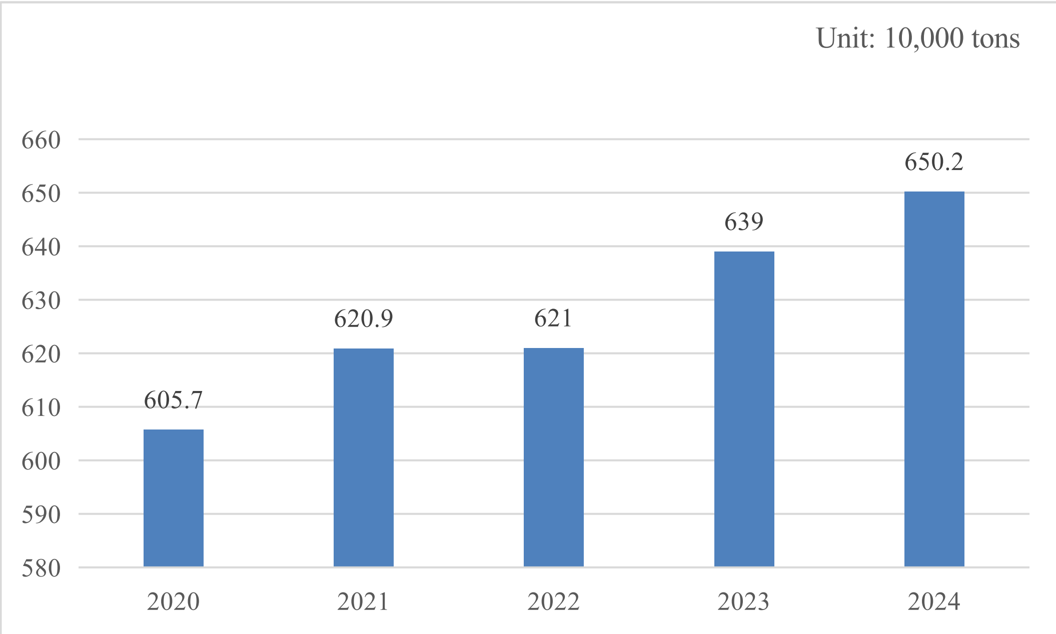

Figure 1. Total grain production in Zhejiang Province, China (2020-2024)

To demonstrate that the application of big data drives the development of precision agriculture, we collected data on the yield of 14 regions in Zhejiang Province before and after the use of digital farms. The following analysis uses hypothesis testing to make a point:

Formulate hypotheses:

$$H_0: \mu_1 \geq \mu_2$$

(*The use of digital farms has no significant impact on the increase of food production*)

$$H_0: \mu_1 < \mu_2$$

(*The use of digital farms has a significant impact on the increase of food production*)

Argumentation process:

Conclusion: $P = 0.35 < \alpha = 0.05$ can be seen from the analysis (**Table 1**). Based on the results obtained, the following judgment can be made: The P-value falls into the rejection domain. Therefore, there is no good reason for the null hypothesis to be true; it can be assumed that the use of digital farms has a significant impact on the increase in food production.

Table 1. Hypothesis paired samples test by SPSS analysis

	Mean	Sted deviation	Std error mean	Lower	Upper	t	df	Sig
Before using digital After using digital farming	8464.17857	13458.19002	16234.70614	16234.70614	693.65100	2353	13	0.035

1.3. Optimizing resource allocation to achieve sustainable development

Zhejiang Province has achieved the efficient allocation of agricultural resources through digital tools [5]. For example, the smart agriculture cloud platform and the "Zhejiang Agricultural Code." In addition, as a digital ID card for agricultural subjects and agricultural products, the "Zhejiang Agricultural Code" realizes the resource optimization of the whole chain of agricultural production through data integration and sharing. The Internet of Things (IOT), big data, and artificial intelligence (AI) technologies are widely used in precision agriculture to promote sustainable agricultural development [6]. At the same time, the intelligent irrigation system automatically adjusts the amount of irrigation according to soil moisture and crop water demand, saving water resources.

2. Problems in precision agriculture with big data applications

2.1. Data sharing and integration

There are many challenges in the sharing and integration of big data in precision agriculture. On the one hand, there are obstacles to data sharing, as data owners are unwilling or unable to share data due to security and privacy concerns, unclear distribution of benefits, differences in standards and norms, and insufficient legal protection. On the other hand, data integration is difficult, data sources are scattered in multiple departments and fields, making them hard to collect, technical obstacles are brought about by the inconsistency of technical platforms in various places, and the quality of data is uneven due to complex terrain.

2.2. Data quality and standards issues

Big data helps precision agriculture face the dual dilemma of data quality and standards. On the other hand, the complex terrain and diversified agricultural industries make it difficult to ensure the accuracy of data collection, the timeliness of update is poor, and the operation of some farmers is not standardized, leading to frequent errors, missing data, or lags in soil, climate, and crop growth data, which cannot provide a reliable basis for agricultural decision-making. On the other hand, the equipment used by agricultural operators in the province varies greatly, the data formats and units are inconsistent, and the classification of agricultural data is not clearly defined, this leads to the difficulty of data aggregation and integration, which greatly restricts the in-depth application of big data in precision agriculture and hindering its progression to a higher stage of development.

2.3. The development of major digital agriculture regions is unbalanced

In Zhejiang Province, the application of big data to precision agriculture has an obvious problem of unbalanced regional development (**Figure 2**) [7]. On the one hand, Hangzhou, Jiaxing, and other regions with relatively developed economies and concentrated scientific and technological resources have made remarkable achievements in the construction of digital agricultural factories and future farms by their abundant capital, technology and talent advantages. On the other hand, some economically underdeveloped areas such as Lishui and Quzhou are located in mountainous areas, limited by factors such as insufficient capital investment, lack of professional talents, and weak infrastructure, the development of big data precision agriculture lags, agricultural production still relies more on traditional experience, less application of intelligent equipment, poor data collection and processing capabilities, and the gap between regions significantly hinders the overall coordinated promotion of precision agriculture in

Zhejiang Province.

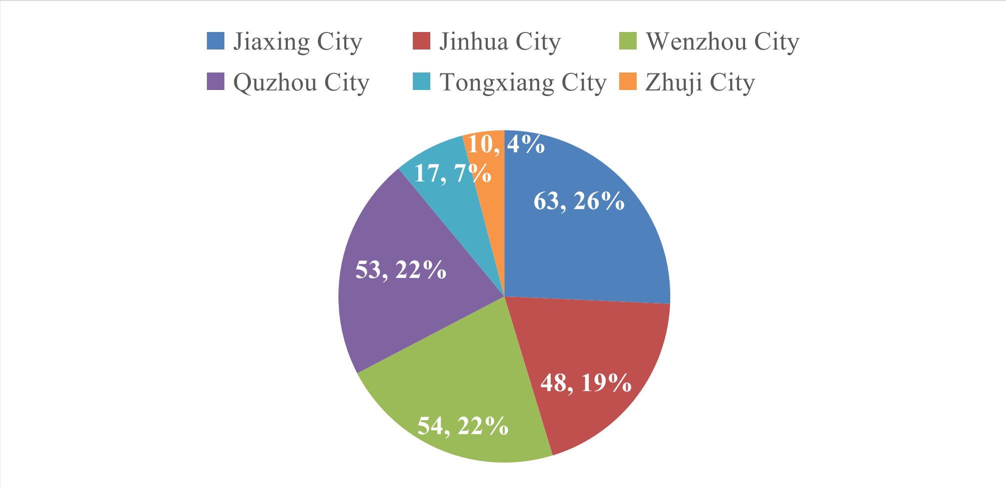

Figure 2. Number of digital farms in Zhejiang Province, China, by region in 2024

3. The practical basis for the application of big data in precision agriculture

3.1. The application of various technologies provides support for the application of big data in precision agriculture

The application of big data in precision agriculture has a solid technical foundation [8]. Firstly, high-precision sensors, UAVs (unmanned aerial vehicles), aerial photography, and satellite remote sensing are widely used to accurately collect data on farmland, soil, meteorology, and crop growth, providing rich material for subsequent analysis. Then, with the developed 5G network covering the countryside, relying on the Internet of Things to realize the intelligent management and control of agricultural machinery and irrigation systems to ensure high-speed and stable data transmission. Finally, the local cloud computing platform provides massive storage support with the help of continuously optimized big data analysis tools and algorithms and uses machine learning and other technologies to dig deep into information, providing a scientific basis for precision agriculture decision-making and facilitating the comprehensive development of Zhejiang's precision agriculture.

3.2. The data resource base provides a guarantee for the application of big data in precision agriculture

The data resource base lays a solid foundation for the precise empowerment of agriculture by big data. For example, Zhejiang Mobile's "Digital Field" project uses high-precision sensors to collect soil temperature, humidity, pH, etc. in Nanxun, Huzhou, and optimizes fertilization based on soil data. Collect meteorological information with the help of small weather stations to guide agricultural adjustments. Jiaxing Tongxin Seedling Digital Agriculture Factory integrates multiple technologies to monitor and control the growth trend of crops; Ningbo Fenghua's "Water Garden" AI system identifies diseases and intelligently regulates them according to crop and environmental data.

3.3. Demand for high-quality agricultural industry

In Zhejiang Province, there is a strong demand for the application of big data in precision agriculture. On the one hand, local consumers have stringent requirements for the quality of agricultural products, focusing on the characteristics of taste, nutrition, and green safety, prompting agricultural producers to use big data to precisely track the whole process of agricultural products, optimize production conditions based on soil, climate and other data, and ensure the quality and stability of products [9]. On the other hand, land and water resources are scarce in Zhejiang, and big data can assist in precise fertilization and optimizing irrigation based on soil nutrients, weather forecasts and other information, thereby improving resource utilization efficiency.

According to a questionnaire survey of 1,000 consumers (**Table 2**), 58% of consumers attach great importance to the taste of agricultural products, as shown in **Figure 3**.

Table 2. Consumers' attention to the taste of agricultural products

		Frequency	Percent	Valid percent	Cumulative percent
	Very much taken seriously	580	58.0	58.0	58.0
	Pay more attention	320	32.0	32.0	90.0
Valid	General	80	8.0	8.0	98.0
	Not much attention	20	2.0	2.0	100.0
	Total	1000	100.0	100.0	

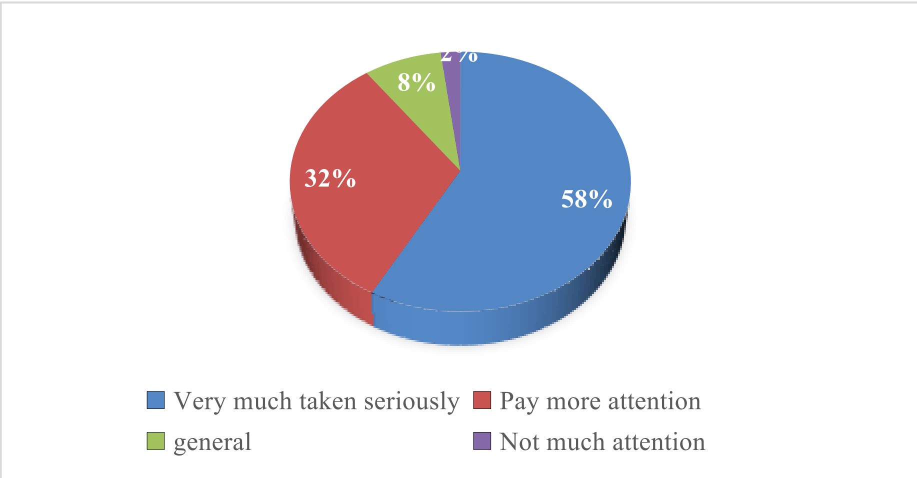

Figure 3. Proportion of consumers attaching importance to the taste of agricultural products

4. The path selection of big data applied to precision agriculture

4.1. Data collection and integration

To apply big data to precision agriculture, data collection and integration are the foundation and support of everything. On the one hand, data collection is diverse and sophisticated. The sensor network is like the "nerve endings" of the farmland, monitoring soil moisture, temperature, nutrients, light, gas, and other conditions in real time and accurately feeding back the microenvironment of crop growth. On the other hand, data integration is efficient and orderly [10]. First, build an agriculture-specific big data platform and aggregate and store multi-source data such as sensors, remote sensing, agricultural machinery, meteorology, and traceability according to unified standards. Then, the combination of algorithms and manual methods is utilized to clean and preprocess the data, eliminate errors and redundancy, correct format deviations, and enhance data availability.

4.2. Analysis of data

If data collection and integration is the foundation, then data analysis is the essence. First, build a dedicated platform for agricultural big data, and aggregate data from various sources such as sensors, remote sensing, agricultural machinery, meteorology, and traceability according to unified standards; Eliminate duplicates, errors, and incomplete data, calibrate deviations, and unify the format to make the data pure and usable; With the help of machine learning and deep learning cutting-edge technologies, we can mine internal correlations. Break the boundaries of departments, institutions, and subjects, establish a data sharing ecology, and the government, scientific research, enterprises, and farmers can access and share according to their authority, collaboratively contributing to the development of precision agriculture.

4.3. Decision support and risk management

In the field of precision agriculture, big data provides a scientific basis for decision-making. By integrating real-time data such as soil and climate collected by field sensors, crop growth dynamic images obtained by satellite and UAV remote sensing, and multi-source information including agricultural machinery operation records, data mining and machine learning algorithms are employed for in-depth analysis to accurately determine the current growth status of crops, required nutrients and water, thereby guiding farmers on the optimal times for watering, fertilizing, and sowing seeds, as well as selecting the most suitable crop varieties.

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Disclosure statement

The authors declare no conflict of interest.

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