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MEASUREMENT AND ANALYSIS OF DIGITAL AGRICULTURE DEVELOPMENT: A CASE STUDY OF ANHUI PROVINCE

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Abstract: The application of digital technology is increasingly extensive, which has injected new vitality into China's traditional agriculture. Measurement agricultural digitization is of great significance for promoting agricultural development. In this paper, the index system of agricultural digital development in Anhui Province is constructed, the level of agricultural digital development in Anhui Province is calculated based on the entropy method, and the tire index is used to analyze the regional differences. The results show that the agricultural digital development level in Anhui Province increases year by year, and in Anhui Province, the low investment of agricultural capital assets is the biggest problem of agricultural digital development.
Keywords: Digital agriculture; Entropy method; Comprehensive score; Horizontal measure

1 INTRODUCTION

Agricultural digital transformation stands as a core global strategy for addressing food security, resource constraints, and climate change. Digital transformation has become a vital means for advancing agricultural modernization[1], and significant regional disparities exist in how digital rural development promotes high-quality agricultural growth[2]. However, existing research predominantly focuses on national or macro-regional scales, lacking detailed characterizations of areas with typical agricultural ecological and economic heterogeneity—particularly in a country like China, where regional disparities are pronounced[3,4]. This scale deficiency constrains our deep understanding of the spatial complexity and diverse mechanisms underlying digitally driven agricultural transformation.

Scholars have conducted a series of studies on the digital transformation of agriculture. Based on six dimensions including the digital agriculture development environment and digital agriculture information infrastructure, Zhang Hong et al.[5]constructed an evaluation index system for agricultural digitalization development, assessing the digitalization levels of agriculture across China's 31 provinces from 2015 to 2019. Fan Jin and Zhang Jinxing[6] employed the entropy-weighted TOPSIS method to assess the level of agricultural digitalization development, and utilized standard deviation ellipses and kernel density estimation to examine its temporal trends and spatial distribution patterns. Gao Yiming[7] proposed indicators and methods for measuring agricultural digitalization development levels using the Ghosh model within an input-output framework under the input-output framework, and conducted actual measurements of agricultural digitalization development levels across China's 31 provinces (municipalities and autonomous regions) during 2002–2020, employing kernel density estimation and Dagum Gini coefficient decomposition methods to analyze the spatiotemporal characteristics of agricultural digitalization development. Yi Jiabin et al.[8] analyzed the driving factors of agricultural digital transformation from the perspective of innovation ecosystem theory and found that these factors encompass four dimensions: institutional support at the national policy level, value-driven forces within the agricultural industry, developmental momentum from new agricultural business entities and technology enterprises, and demand-side traction driven by consumers' aspirations for a better life.

As a major grain-producing region in China and a pivotal component of the Yangtze River Delta's agricultural integration, Anhui Province exemplifies the digital transformation of agriculture. The province combines large-scale grain production with rapid urbanization, while simultaneously facing multiple challenges including structural labor shortages in agriculture and intensifying resource and environmental pressures[9]. Despite local governments having promoted initiatives such as “Digital Anhui Farmers,” there remains a lack of a systematic, quantifiable, and comparable evaluation framework to objectively reflect the true level, structural characteristics, and spatial differentiation of their digital development. Therefore, this paper aims to construct an evaluation index system for agricultural digitalization development tailored to Anhui Province's agricultural ecology and socioeconomic characteristics. It measures the level of agricultural digitalization development, analyzes regional disparities, and proposes policy recommendations to promote Anhui's agricultural digitalization. This work provides insights for the gradual advancement of agricultural digitalization and quality enhancement in Anhui, as well as for the comprehensive revitalization of rural areas.

2 RESEARCH METHODS

This paper conducts a systematic review and synthesis of literature related to agricultural digitalization development and, in conjunction with the status of agricultural development in Anhui Province, clarifies the theoretical and practical

context of the research. Using the entropy method and a comprehensive evaluation model, the study measures the level of agricultural digitalization development in Anhui Province from 2013 to 2022. On this basis, the Theil index is employed to analyze regional disparities in agricultural digitalization development across different areas. Finally, recommendations are proposed for advancing agricultural modernization in Anhui Province.

2.1 Construction of the Evaluation Indicator System

The selection of indicators for assessing agricultural digitalization in this study is informed by a comprehensive review of domestic scholarly work on indicator systems pertaining to the digital economy, agricultural informatization, and high-quality agricultural development. Grounded in the key determinants of agricultural digitalization, the proposed evaluation framework consists of 19 indicators categorized into six dimensions. These indicators encompass: total agricultural machinery power; rural electricity consumption; fixed-asset investment in transportation, warehousing, and postal services; fixed-asset investment in scientific research and technical services; fixed-asset investment in information transmission, software, and information technology services; rural broadband subscribers; mobile telephone exchange capacity; employment in agricultural scientific research and technical services; employment in information transmission, software, and information technology services; local government expenditure on science and technology; local government expenditure on agriculture; local government expenditure on education; effectively irrigated area; pesticide consumption; chemical fertilizer application; agricultural plastic film usage; gross output value of agriculture, forestry, animal husbandry, and fishery; e-commerce procurement volume; and e-commerce sales volume. The complete evaluation indicator system for agricultural digitalization is summarized in Table 1.

Table 1 Indicators Selected for Agricultural Digitalization Development Assessment

Target Layer	Criterion Layer	Indicator	Positive/Negative Indicator
Evaluation Indicators for Agricultural Digitalization Development Level	Agricultural Development Environment	Total Agricultural Machinery Power (kWh)（X1）	+
		Rural Electricity Consumption (10,000 kWh)（X2）	+
		Fixed-Asset Investment in Transportation, Warehousing, and Postal Services (100 million yuan)（X3）	+
		Fixed-Asset Investment in Scientific Research and Technical Services (100 million yuan)（X4）	+
		Fixed-Asset Investment in Information Transmission, Software, and Information Technology Services (100 million yuan) (X5)	+
	Agricultural Information Infrastructure	Rural Broadband Subscribers (10,000 households) (X6)	+
		Mobile Telephone Exchange Capacity (10,000 subscribers) (X7)	+
	Rural Human Resources	Employment in Scientific Research and Technical Services (10,000 persons) (X8)	+
		Employment in Information Transmission, Software, and Information Technology Services (10,000 persons) (X9)	+
	Government Support for Agriculture	Local Government Expenditure on Science and Technology (10,000 yuan) (X10)	+
		Local Government Expenditure on Agriculture (10,000 yuan) (X11)	+
		Local Government Expenditure on Education (10,000 yuan) (X12)	+
	Agricultural Green Development	Effective Irrigated Area (1,000 hectares) (X13)	+
		Agricultural Pesticide Usage (tons) (X14)	-
		Chemical Fertilizer Application (tons) (X15)	-
		Agricultural Plastic Film Usage (tons) (X16)	-
		Gross Output Value of Agriculture, Forestry, Animal Husbandry, and Fishery (10,000 yuan) (X17)	+
	Agricultural Industrial Benefits	E-commerce Procurement Volume (100 million yuan) (X18)	+

		E-commerce Sales Volume (100 million yuan) (X19)	+

2.2 Entropy Method

This study constructs a six-dimensional digital agriculture evaluation system to quantify the comprehensive development level of agricultural digitalization in Anhui Province. The entropy method is applied to determine the weight of each indicator within the framework. Composite scores are then calculated based on these weights, enabling an objective and scientifically grounded assessment of digital agriculture development across Anhui's 16 prefecture-level cities through score ranking.

The fundamental principle of the entropy weight method is that entropy and information content increase as uncertainty rises, leading to a higher weight for the corresponding indicator. Conversely, as uncertainty decreases, entropy and information content diminish, resulting in a lower indicator weight. The implementation process involves four steps. First, the original data matrix is standardized to eliminate scale effects, with positive and negative indicators adjusted for directional consistency. Second, the proportion matrix of sample values under each indicator is calculated. Third, the information entropy of each indicator is measured using the entropy formula, where a smaller entropy value indicates higher data dispersion. Finally, indicator weights are determined by normalizing the information utility values (1 – entropy value). A higher utility value corresponds to a greater weight, thereby quantifying indicator importance and ensuring that the weight allocation reflects the inherent statistical patterns of the data. In this study, the evaluation indicator data are multiplied by their respective weights to derive the comprehensive digital economy index and the comprehensive agricultural digitalization score for Anhui Province.

Based on panel data covering 16 cities in Anhui Province from 2013 to 2022, this study applies the entropy method to calculate indicator weights, as presented in Table 2.

Table 2 Weight Distribution of the Digital Agriculture Development Evaluation Indicator System

	Primary Indicator	Secondary Indicator	Weight
Evaluation Indicators for Agricultural Digitalization Development Level	Agricultural Development Environment	Total Agricultural Machinery Power (kWh)（X1）	-0.0292
		Rural Electricity Consumption (10,000 kWh)（X2）	-0.0239
		Fixed-Asset Investment in Transportation, Warehousing, and Postal Services (100 million yuan)（X3）	-0.054
		Fixed-Asset Investment in Scientific Research and Technical Services (100 million yuan)（X4）	-0.1094
		Fixed-Asset Investment in Information Transmission, Software, and Information Technology Services (100 million yuan) (X5)	-0.1702
	Agricultural Information Infrastructure	Rural Broadband Subscribers (10,000 households) (X6)	-0.0428
		Mobile Telephone Exchange Capacity (10,000 subscribers) (X7)	-0.0317
	Rural Human Resources	Employment in Scientific Research and Technical Services (10,000 persons) (X8)	-0.0987
		Employment in Information Transmission, Software, and Information Technology Services (10,000 persons) (X9)	-0.128
		Local Government Expenditure on Science and Technology (10,000 yuan) (X10)	-0.1089
	Government Support for Agriculture	Local Government Expenditure on Agriculture (10,000 yuan) (X11)	-0.0289
		Local Government Expenditure on Education (10,000 yuan) (X12)	-0.0355
		Effective Irrigated Area (1,000 hectares) (X13)	-0.0234
		Agricultural Pesticide Usage (tons) (X14)	-0.0355
	Agricultural Green Development	Chemical Fertilizer Application (tons) (X15)	-0.028
		Agricultural Plastic Film Usage (tons) (X16)	-0.0518
		Gross Output Value of Agriculture, Forestry, Animal Husbandry, and Fishery (10,000 yuan) (X17)	-0.0216
	Agricultural Industrial Benefits	E-commerce Procurement Volume (100 million yuan) (X18)	-0.0978

E-commerce Sales Volume (100 million yuan) (X19)	-0.1054

2.3 Theil Index

The Theil index (Theil, 1967) is a widely used tool for analyzing regional disparities in income levels, with regional inequality remaining a key topic of academic and policy discourse. The magnitude of the Theil index is positively correlated with the degree of dispersion in the distribution of the studied variable across regions—a smaller index indicates lower disparity, while a larger value reflects greater inequality. Time-series analysis using the Theil index enables a clear observation of the dynamic evolution of disparities across years. In this study, the Theil index is applied to examine regional differences in the level of agricultural digitalization development across Anhui Province.

$$Theil = \frac{1}{N \sum_{i=N} \frac{y_i}{u} \ln \frac{y_i}{u}} \quad (1)$$

Where N is the total number of regions, u represents the average level of digital agriculture development, and y_i refers to the development level of individual cities.

2.4 Data Sources

To comprehensively analyze the current status of agricultural digitalization development in Anhui Province and conduct a quantitative assessment of its level, this study selects data from the period 2013–2022 for all 16 prefecture-level cities in the province. The data are primarily sourced from the *China Rural Statistical Yearbook* and the annual *Anhui Statistical Yearbook*. In cases where certain indicators were missing for specific cities or years, linear interpolation was applied to impute the missing values. To eliminate the influence of differing measurement units on the evaluation results, all indicator values were standardized using the range normalization method, transforming them into dimensionless scores ranging from 0 to 1.

3 RESULTS

3.1 Temporal Evolution of Agricultural Digitalization Development in Anhui Province

This study applies the min-max normalization method to standardize the 19 secondary indicators of agricultural digitalization development. A comprehensive evaluation approach is then used to calculate the composite scores of agricultural digitalization for the 16 prefecture-level cities in Anhui Province from 2013 to 2022.

Table 3 Comprehensive Scores and Rankings of Agricultural Digitalization Development in Cities of Anhui Province, 2013–2022

Region	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Mean	Ranking
Hefei	0.39	0.45	0.50	0.58	0.56	0.65	0.68	0.90	1.00	1.08	0.68	1
Fuyang	0.19	0.20	0.21	0.23	0.24	0.26	0.28	0.29	0.30	0.31	0.25	2
Suzhou	0.19	0.20	0.21	0.22	0.21	0.22	0.23	0.29	0.24	0.25	0.23	3
Wuhu	0.12	0.13	0.15	0.17	0.18	0.19	0.21	0.25	0.31	0.35	0.21	4
Chuzhou	0.13	0.14	0.14	0.15	0.15	0.18	0.22	0.20	0.20	0.22	0.17	5
Bengbu	0.14	0.14	0.15	0.15	0.15	0.16	0.16	0.22	0.16	0.17	0.16	6
Bozhou	0.13	0.13	0.14	0.12	0.15	0.16	0.16	0.22	0.17	0.19	0.16	7
Lu'an	0.15	0.16	0.13	0.13	0.13	0.14	0.14	0.16	0.18	0.21	0.15	8
Anqing	0.13	0.14	0.13	0.14	0.14	0.14	0.15	0.15	0.16	0.17	0.15	9
Ma'anshan	0.07	0.08	0.09	0.10	0.11	0.09	0.10	0.19	0.16	0.17	0.12	10
Huainan	0.07	0.07	0.11	0.12	0.12	0.12	0.12	0.13	0.13	0.14	0.11	11
Xuancheng	0.07	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.10	0.11	0.09	12
Huaibei	0.04	0.04	0.05	0.08	0.06	0.06	0.06	0.06	0.08	0.10	0.06	13
Tongling	0.01	0.02	0.04	0.04	0.05	0.05	0.04	0.10	0.05	0.06	0.05	14
Chizhou	0.03	0.03	0.03	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	15
Huangshan	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.05	0.05	0.04	16

As presented in Table 3, most cities show an upward trend in 2022 compared with 2013. Tongling, Chizhou and Huangshan maintained relatively stable development with only modest growth. The provincial average level of industrial development was 0.17, while the regional averages of agricultural digitalization were 0.09 in southern Anhui, 0.29 in central Anhui, and 0.16 in northern Anhui. Based on the ten-year panel data of the 16 cities in Anhui Province, Hefei recorded the highest level of agricultural modernization, with an average score of 0.68, whereas Huangshan had the lowest average of 0.04. Overall, central Anhui exhibited the highest level of modernization, followed by northern Anhui, with southern Anhui ranking the lowest. This regional disparity may be attributed to the emphasis on modern technological development in central Anhui, represented by Hefei, which contributes to its higher agricultural modernization. In contrast, southern Anhui has prioritized tertiary industries such as tourism, resulting in relatively lower levels of agricultural modernization compared to the northern and central regions.

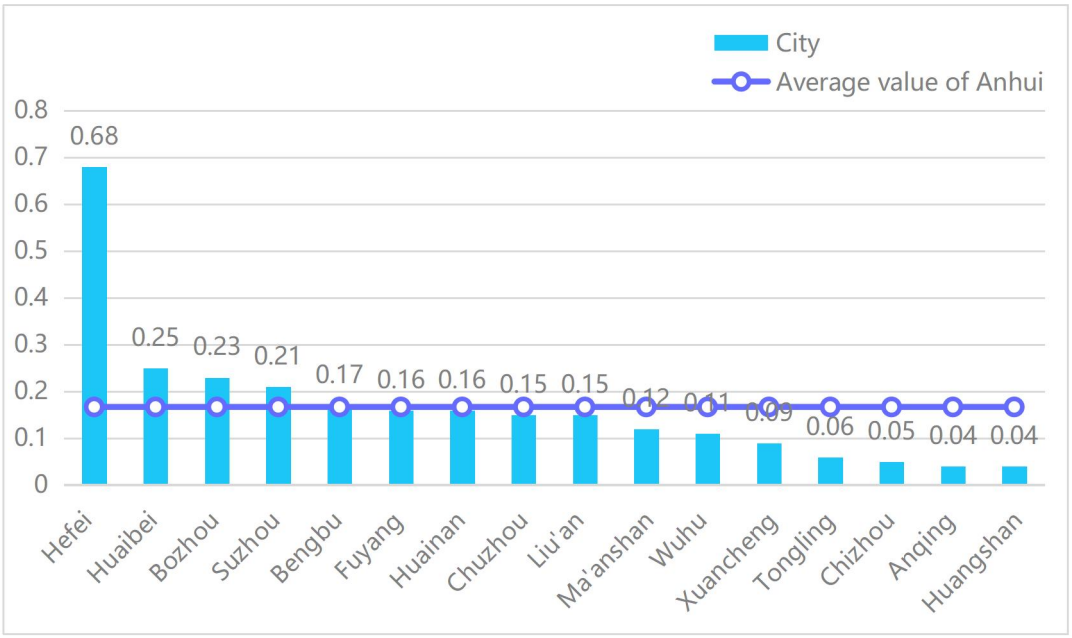

Figure 1 Average Comprehensive Scores of Agricultural Digitalization for 16 Cities in Anhui Province, 2013–2022

As illustrated in Figure 1, notable disparities exist in the composite scores of agricultural digitalization across cities in Anhui Province. The provincial average stands at 0.17, whereas Hefei exhibits a markedly higher level of digital agriculture development, with a composite score of 0.68. In contrast, the average scores for Fuyang, Huainan, Chuzhou, Lu'an, Ma'anshan, Wuhu, Xuancheng, Tongling, Chizhou, Anqing, and Huangshan are 0.16, 0.16, 0.15, 0.15, 0.12, 0.11, 0.09, 0.06, 0.05, 0.04, and 0.04, respectively—all falling below the provincial mean. This pattern suggests that, compared to the national index of digital agriculture development, most cities in Anhui Province are still in the early stages of agricultural digitalization advancement.

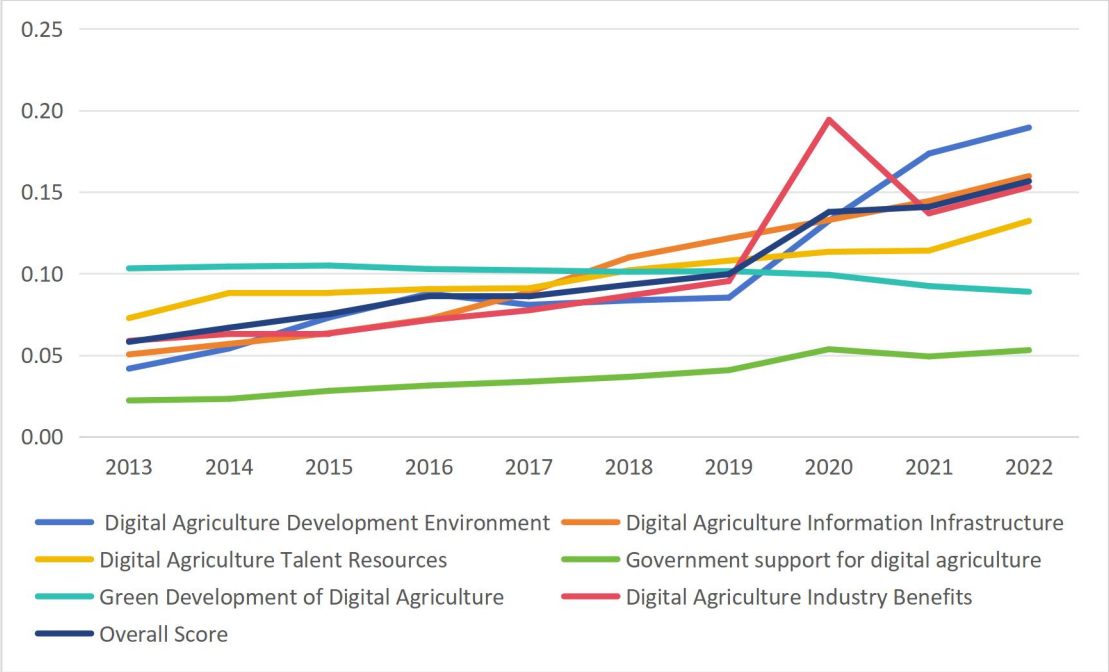

Figure 2 Scores of Various Dimensions in Agricultural Digitalization Development Across Cities in Anhui Province, 2013–2022

Figure 2 presents the trends in the comprehensive score of agricultural digitalization development in Anhui Province and its six constituent dimensions from 2013 to 2022. The overall score for agricultural digitalization in Anhui shows a gradual upward trend. With the exception of green development in digital agriculture, all five other dimensions exhibit increases: the digital agriculture development environment rose from 0.04 to 0.19, digital agriculture information infrastructure increased from 0.05 to 0.16, digital agriculture human resources grew from 0.07 to 0.13, digital agriculture government support saw a modest rise from 0.02 to 0.05, and digital agriculture industrial benefits increased from 0.06 to 0.15, peaking at 0.19 in 2020. In contrast, green development in digital agriculture remained relatively

stable. Among the six dimensions, the digital agriculture development environment achieved the highest score and demonstrated the fastest growth.

4.2 Regional Disparity Analysis of Digital Agriculture Development Levels

For regional disparity analysis, the 16 cities in Anhui Province are classified into three regions: Southern, Central, and Northern Anhui. Southern Anhui includes Huangshan, Chizhou, Ma'anshan, Tongling, Xuancheng, and Wuhu. Central Anhui encompasses Hefei, Anqing, Chuzhou, and Lu'an—cities with notable economic development potential. Among them, Hefei, as the provincial capital, has experienced rapid growth in recent years, evolving into a key economic center both within the province and nationwide. Northern Anhui comprises Fuyang, Suzhou, Huaibei, Bozhou, Bengbu, and Huainan, a region characterized mainly by plains and a relatively well-developed agricultural sector. Based on the average comprehensive scores, a line chart is presented below.

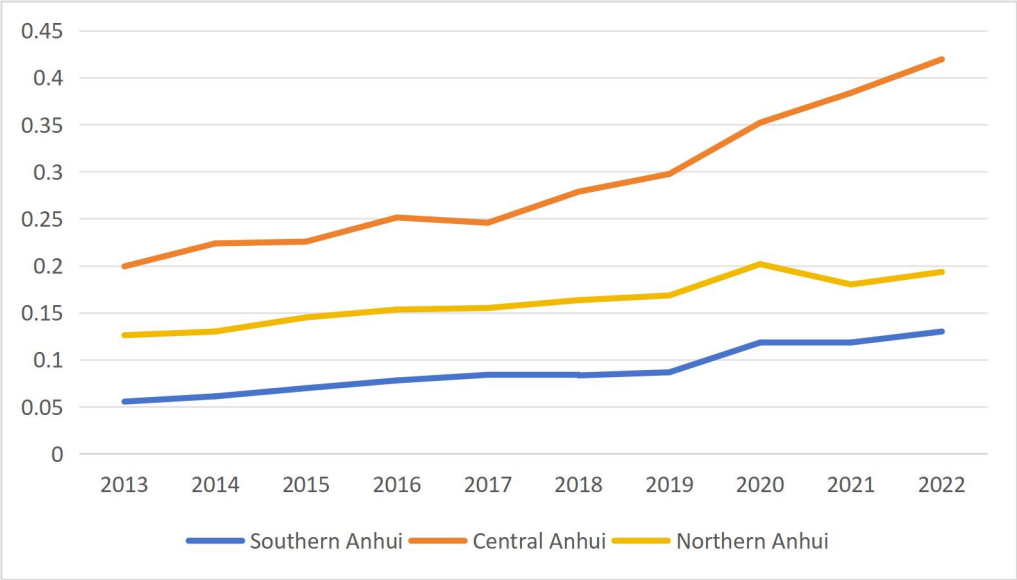

Figure 3 Line Chart of Agricultural Digitalization Development in Northern, Central, and Southern Anhui

As shown in Figure 3, agricultural digitalization in southern Anhui has progressed slowly, while central Anhui has exhibited the most rapid and substantial growth. In contrast, northern Anhui has maintained a relatively stable development trajectory.

The slower pace of digitalization in southern Anhui may be attributed to geographical constraints, economic foundations, and resource availability. The region's mountainous terrain and less-developed transportation infrastructure have limited the adoption and diffusion of digital technologies in agriculture. Furthermore, its comparatively weaker economic growth and scarcity of financial and technical support have also impeded digital progress.

In contrast, central Anhui has demonstrated significant achievements in agricultural digitalization, largely due to its stronger economic base and well-developed agricultural infrastructure. Located primarily on plains with efficient transportation networks and abundant agricultural resources, the region offers favorable conditions for implementing digital technologies. Additionally, central Anhui has actively introduced and fostered agricultural digital technologies while promoting agricultural innovation, which has accelerated the advancement of digitalization in the sector.

Northern Anhui has maintained steady progress in agricultural digitalization, albeit at a slower pace than central Anhui. The region continues to advance its digital agricultural initiatives, focusing on enhancing agricultural infrastructure, improving production efficiency, and exploring context-specific models for digital agricultural development.

In summary, while southern, central, and northern Anhui display varying levels of agricultural digitalization, all three regions are actively promoting digital transformation to enhance agricultural productivity and quality. Moving forward, continued technological progress and increased policy support are expected to create broader opportunities for agricultural digitalization across Anhui.

By categorizing Anhui's 16 cities into southern, central, and northern regions, this study highlights the distinct characteristics and challenges of each area. Future development efforts should adopt tailored policies and measures to promote coordinated regional growth, adapt to local conditions, and support comprehensive socioeconomic progress.

Using the Theil index, this study further measures and analyzes agricultural digitalization across Anhui. As a major agricultural province, the digital transformation of agriculture is crucial for advancing agricultural modernization in Anhui. The Theil index provides a comprehensive lens to examine the current status, identify challenges, and anticipate future trends in the province's agricultural digitalization. The results are summarized in the table 4 below.

Table 4 Theil Index of Agricultural Digitalization Development Level

Year	Theil Index	Theil Index Growth Rate

2013	0.015	-
2014	0.022	0.297
2015	0.031	0.286
2016	0.121	0.745
2017	0.113	-0.066
2018	0.225	0.496
2019	0.294	0.235
2020	0.631	0.534
2021	0.692	0.088
2022	0.860	0.195

As presented in Table 4, the Theil index measuring agricultural digitalization development in Anhui Province ranges from 0.015 to 0.860 during the study period. A clear upward trend is observed, with the index rising from 0.015 in 2013 to 0.860 in 2022. Notably, the highest growth rate occurred in 2020, reflecting accelerated progress across multiple dimensions of agricultural development in the province's later stages. This enhancement can be attributed to sustained technological innovation, supportive policy measures, and the dedicated efforts of local farmers. Driven by continuous technological advancement, agriculture in Anhui is steadily transitioning from traditional practices to modern, digitally-enabled approaches.

4 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Based on systematically compiled data related to agricultural digitalization in Anhui Province, this study first examines the current status of agricultural digitalization in the region. By integrating indicators across six dimensions—digital agriculture development environment, information infrastructure, human resources, technological support, green development, and industrial benefits—a multi-level evaluation system was constructed. The entropy method was employed to assess the progress of agricultural digitalization, generating composite index scores for each prefecture-level city in Anhui and thereby enabling a quantitative evaluation of the province's agricultural digitalization level. Furthermore, comprehensive evaluation and the Theil index were utilized to analyze regional disparities in agricultural digitalization across Anhui. The principal findings are summarized as follows:

(1) Analysis of the current state and measurement outcomes reveals that although Anhui is traditionally endowed with the resources of a major agricultural province, the advancement of agricultural digitalization has remained gradual in recent years. Consequently, accelerating agricultural modernization in Anhui represents an urgent imperative.

(2) Empirical results highlight that inadequate investment in agricultural capital assets constitutes a significant factor constraining the pace of agricultural modernization in Anhui. Investment plays a pivotal role in fostering agricultural digitalization, which demands substantial financial resources for technological research, equipment procurement, talent cultivation, and related domains. As a leading agricultural nation, China has maintained considerable investment in agriculture from both governmental and societal channels. These investments furnish a solid material foundation for agricultural digitalization, catalyzing the research, development, and deployment of associated technologies and thereby propelling overall progress in this field.

(3) Overall, the modernization level is highest in central Anhui, followed by northern Anhui, with southern Anhui exhibiting the lowest level. This pattern may be attributable to the emphasis on modern technological development in central Anhui—exemplified by Hefei—which has elevated agricultural modernization in the region. In contrast, southern Anhui has prioritized tertiary industries such as tourism, resulting in comparatively lower agricultural modernization relative to the northern and central regions. Moving forward, policy measures should focus on fostering balanced development across all cities in Anhui to achieve coordinated and inclusive growth.

5.2 Recommendations

5.2.1 Strengthen agricultural infrastructure to enhance production efficiency

The government should take the lead in expanding rural infrastructure investment and encourage diversified investment in agriculture and rural areas to facilitate capital accumulation and asset development. Policy frameworks should be refined to increase agricultural investment from both rural communities and individuals. This includes ensuring a designated proportion of rural savings is directed toward agriculture, incentivizing farmers to contribute labor for infrastructure improvement, and actively encouraging municipal enterprises to increase investment in key agricultural assets.

5.2.2 Increase investment in agricultural technology innovation to drive progress

Scientific research in Anhui should be closely aligned with agricultural development needs, with an emphasis on regional characteristics. Increased investment in technology should address local agricultural demands, while a research mechanism that integrates modern industrial and agricultural technologies should be enhanced. This approach would optimize the use of Anhui's resources and attract research talent. Agricultural research resources should be strategically allocated to support regions with slower development, thereby promoting balanced progress and improving agricultural technology dissemination in these areas.

5.2.3 Cultivate new agricultural business entities and optimize operational models

Agricultural digitalization requires innovation in both business entities and operational methods. This involves multidimensional optimization through the integration of modern technologies and a departure from traditional operational paradigms to achieve comprehensive digital transformation in agriculture.

5.2.4 Promote labor marketization for balanced resource allocation

The realization of agricultural digitalization should involve the integration of grassland, forestry, industrialization, and modern agricultural sectors. Efforts should focus on developing modern agricultural enterprises and fostering partnerships with contemporary businesses. Through standardized labor contracts and stable employment mechanisms, labor resources can be efficiently and equitably allocated across the agricultural market.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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