Thoughts on Technology-Enabled Smart Agriculture Development Models for Rural Revitalization in Southern China (Postprint)

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Abstract

Rural revitalization constitutes a major task in achieving the great rejuvenation of the Chinese nation. Agriculture forms the foundation of rural areas, and the development of smart agriculture represents an important instrument for realizing rural revitalization. The hilly and mountainous regions of southern China constitute concentrated distribution areas of rocky desertification in the country, with evident disadvantages in agricultural basic conditions, representing a "hard nut to crack" for China' s rural revitalization efforts. During this critical period of consolidating and expanding poverty alleviation achievements while continuously advancing rural revitalization, and against the backdrop of vigorous development in high-tech technologies such as the Internet of Things, artificial intelligence, and big data, how to achieve informatization in the hilly and mountainous areas of southern China, how to chart a rational path for modern agricultural and rural development, and how to utilize agricultural development to promote rural harmony and prosperity for farmers are issues requiring urgent consideration and resolution. This article, grounded in the fundamental current conditions of population, cultivated land, and topography in the hilly and mountainous areas of southern China, conducts an in-depth analysis of the pain points constraining agricultural development in these regions. Centering on the entire process of smart agriculture—including intelligent perception, intelligent communication, intelligent decision-making, and intelligent operations—and leveraging information-based and intelligent means, it proposes concepts and procedures for developing smart agriculture in the hilly and mountainous areas of southern China, formulates a set of smart agriculture development models to facilitate rural revitalization in the south, and demonstrates this approach using Shuicheng District in Guizhou Province as an example, with the aim of comprehensive promotion. Finally, focusing on the shortcomings and challenges

in developing smart agriculture in the hilly and mountainous areas of southern China, it puts forward four development recommendations.

Full Text

Preamble

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Abstract

Rural revitalization is a major task in achieving the great rejuvenation of the Chinese nation. Agriculture is the foundation of rural areas, and developing smart agriculture represents an important means to realize rural revitalization. The southern hilly and mountainous regions constitute China' s primary area of rocky desertification, characterized by pronounced disadvantages in agricultural infrastructure conditions and representing the most challenging "hard nut to crack" in China' s rural revitalization efforts. During this critical period of consolidating and expanding poverty alleviation achievements while continuously advancing rural revitalization, and against the backdrop of vigorous development in high technologies such as the Internet of Things, artificial intelligence, and big data, urgent questions demand attention: How can these hilly and mountainous areas in southern China achieve informatization? What constitutes a rational path for modern agricultural and rural development? How can agricultural development drive rural harmony and prosperity? This article examines the fundamental realities of population, arable land, and topography in southern China' s hilly and mountainous regions, deeply analyzing the pain points that constrain agricultural development there. Focusing on the complete workflow of smart agriculture—intelligent perception, intelligent communication, intelligent decision-making, and intelligent operations—the paper proposes concepts and steps for developing smart agriculture in these regions through information-based and intelligent means. The objective is to formulate a comprehensive smart agricultural development model to support rural

revitalization in southern China, with demonstration through a case study in Shuicheng District, Guizhou Province, in anticipation of broader implementation. Finally, addressing the shortcomings and challenges of smart agriculture development in these regions, four specific recommendations are proposed.

Keywords: smart agriculture, southern hilly and mountainous areas, rural revitalization, industrial development

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1. Overview and Development Bottlenecks in Southern Hilly and Mountainous Areas

1.1 Geographic Distribution and General Characteristics

The southern hilly and mountainous areas of China refer to the vast tropical and subtropical regions south of the Qinling-Huaihe line, primarily including Yunnan, Guizhou, Sichuan, Chongqing, Hubei, Hunan, Guangdong, and Guangxi provinces. These areas constitute the main distribution region of China' s karst topography. As one of the countries with the most diverse karst development types worldwide, China' s karst landforms cover approximately one-third of its total land area, with 540,000 square kilometers of contiguous exposed karst concentrated in the southwest [1]. In these regions, long-term intensive agricultural pressure combined with severe soil erosion from rainstorms has caused extensive bedrock exposure, making the southwestern karst areas China' s primary ecologically fragile zone of rocky desertification. This desertification has drastically reduced or even eliminated land carrying capacity, severely compressing cultivated land resources. Consequently, southern hilly and mountainous areas once became China' s largest contiguous poverty-stricken region—by the end of 2017, impoverished populations accounted for approximately 40% of the national total, with 211 contiguous destitute counties and national key poverty-alleviation counties, characterized by extensive and deep poverty [2].

According to the Third National Land Survey, by the end of 2019, China' s arable land area totaled 1.918 billion mu, with per capita arable land of only 1.36 mu—less than 40% of the world average. Southern hilly and mountainous regions generally have per capita arable land below the national average (Figure 1 [Figure 1: see original paper]). Furthermore, influenced by urbanization and population migration, China' s rural population has declined year by year. In southern hilly and mountainous areas, farmer out-migration for work is common, and the aging process has accelerated significantly, resulting in severe rural labor shortages. In many places, this has even led to varying degrees of farmland abandonment. According to a survey report by the Agricultural Mechanization Management Department of the Ministry of Agriculture and Rural Affairs on agricultural mechanization in typical hilly and mountainous provinces, by the end of 2018, the total agricultural machinery power in these provinces reached 440 million kilowatts, a 21% increase from 2012. However, the comprehensive

mechanization rate for crop cultivation, planting, and harvesting remained below 50%, with southwestern hilly and mountainous areas at only 29%—far below the national average of 69%. This gap remains substantial compared to the urgent demand for mechanization from agriculture, rural areas, and farmers.

1.2 Problems in Agricultural Development

The unique geographic environment and poor agricultural production conditions in southern hilly and mountainous areas have created prominent difficulties. First, agricultural production suffers from low levels of scale and mechanization. Complex terrain, large slopes, and fragmented, scattered plots, combined with lagging infrastructure, make field transfer and cross-regional operations of agricultural machinery difficult. Consequently, large and medium-sized machinery cannot conduct large-scale operations in fields [3]. Second, there is a lack of agricultural machinery compatible with local planting patterns. Small per capita arable land forces farmers to adopt complex grain-cash crop intercropping structures to maximize limited land resources, resulting in diverse crop types and complex cultivation techniques. Existing machinery cannot meet all production needs, while suitable equipment is difficult to develop and has limited promotion, constraining mechanization development in these areas. Third, rural information infrastructure lags behind, with network conditions requiring improvement. Statistics show that as of June 2020, the internet penetration rate gap between urban and rural residents remained 24.1%. In remote mountainous rural areas, harsh natural environments and complex topography result in poor network coverage continuity, failing to meet modern agricultural development needs. Fourth, rural aging is increasingly severe, with low enthusiasm among young adults for agricultural work and serious rural labor shortages. More young people choose to work outside their hometowns, causing continuous loss of agricultural technicians and machinery talent. Accelerated aging has created severe labor shortages, making promotion of new agricultural machinery technologies difficult.

2. Smart Agriculture as a Breakthrough for Rural Development Bottlenecks in Southern China

Agriculture is the foundation of rural areas, and the agricultural development bottlenecks in southern China' s hilly and mountainous regions are inevitably linked to low local agricultural productivity. According to the *Rural Revitalization Strategic Plan (2018-2022)*, the overall requirements for rural revitalization are prosperous industries, ecological livability, civilized rural customs, effective governance, and affluent living. The *National Rural Industrial Development Plan (2020-2025)* clearly states that "industrial revitalization is the primary task of rural revitalization. We must firmly seize opportunities, follow the trend, and accelerate rural industrial development to promote comprehensive rural revitalization." Smart agriculture represents a crucial breakthrough for overcoming agricultural industrial bottlenecks. The *2023 Key Points for*

Digital Rural Development Work, jointly issued by five departments including the Central Cyberspace Affairs Commission and the Ministry of Agriculture and Rural Affairs, points out the need to develop smart agriculture according to local conditions, including accelerating digital transformation of the entire agricultural industry chain and strengthening support from agricultural technology and intelligent equipment. In this new era, supported by high technologies such as the Internet of Things, big data, artificial intelligence, and cloud computing, developing smart agriculture can drive rural information infrastructure construction, enhance agricultural production efficiency, promote rural industrial prosperity, help farmers achieve wealth, realize common prosperity, and play a major leading and driving role in China' s agricultural modernization and rural revitalization strategy.

In the new era, under the guidance of national policies and based on the development status of southern China' s hilly and mountainous areas, we should vigorously develop smart agriculture, fully leverage modern scientific and technological strength, and focus on breaking through bottlenecks encountered in development. For example, we can use intelligent and information-based means to solve problems of labor shortage and aging, promote agricultural mechanization popularization, and facilitate ecological environmental protection. Exploring and practicing systematic solutions suitable for these regions will help promote rural revitalization construction in southern China.

3. Exploring Smart Agriculture Models for Southern Hilly and Mountainous Areas

During this important period of consolidating and expanding poverty alleviation achievements and continuously advancing rural revitalization, and under the strategic direction of national deployment for digital rural construction, we should build upon traditional agriculture' s role in rural poverty alleviation. We must give full play to the driving and leading role of informatization and intelligence in rural revitalization, comprehensively promoting and enhancing modern agricultural and rural development, and promoting comprehensive agricultural upgrading, comprehensive rural progress, and comprehensive farmer development. This article conducts systematic analysis based on the actual conditions of southern hilly and mountainous areas to explore a suitable smart agriculture development model, using Shuicheng District as a demonstration case for broader promotion.

3.1 Prioritize Land Use Planning and Preparation

Land planning and utilization are primary considerations for agricultural development in southern hilly and mountainous areas. The Ministry of Agriculture and Rural Affairs' Agricultural Mechanization Management Department conducted surveys in over 700 counties in these regions. Sample county data shows that three constraining factors—"fragmented plots resulting in low machine oper-

ation efficiency," "lagging construction of farm roads preventing machine access," and "excessive plot slopes preventing machine operation" —each had average selection frequencies above 49%, representing the main constraints on agricultural mechanization development [5].

First, relatively large and suitable land should be leveled for mechanized operations. Drawing from South Korea' s farmland mechanization transformation experience, scattered and fragmented land within a certain range can be reorganized through land exchange and consolidation to facilitate farm management and mechanized operations. After more than 40 years of farmland consolidation, South Korea' s dryland crop mechanization rate increased significantly, reaching 60.2% by 2019 [6]. Second, land consolidation must strengthen ecological protection. Improper consolidation may cause soil erosion and trigger ecological problems. Therefore, before land consolidation, remote sensing, big data, and other technologies should be used to collect and systematically analyze various data that may cause ecological impacts, enabling formulation of scientifically sound implementation plans [7]. For land with excessive slopes unsuitable for mechanized cultivation, alternative ecological protection approaches should be adopted, such as returning farmland to forests and grasslands and developing fruit forestry and animal husbandry.

3.2 Establish County-Level Smart Agriculture Big Data Centers and Integrated Application Platforms

Smart Agriculture Big Data Center. Based on rural land consolidation planning, county-level smart agriculture big data centers and integrated application platforms should be established to serve agricultural intelligent systems, with villages as application nodes, data collection units, and practical operation units. The big data center develops agricultural intelligent software systems based on supercomputing centers and computing networks. Using modern information collection, transmission, and monitoring equipment, along with IoT, sensors, wireless transmission, and data storage technologies, massive data from pre-production, mid-production, and post-production stages are collected, transmitted, and stored in information databases. Subsequently, big data and artificial intelligence technologies analyze and model this data to generate decision-making guidance for agricultural production. This system connects various types of agricultural production sites across the region, serving as the decision-making hub for regional agricultural production.

Smart Agriculture Integrated Application Platform. This platform is an integrated application platform based on agricultural big data that integrates the primary, secondary, and tertiary agricultural industries. Centered on full-chain monitoring and information services for agricultural production, processing, and sales, it provides terminal applications in cloud service form for users including farmers, agricultural technicians, family farms, enterprises, and consumers, thereby enhancing agricultural production scheduling, decision-making, management, and service capabilities throughout the entire chain [8].

3.3 Agricultural Intelligent System Based on Full-Factor Simulation

A county and its associated farmland can establish an agricultural intelligent system. Using information technology as the primary means, this system creates a "digital twin" of agricultural production in information space through data collection throughout the agricultural production process. It moves agricultural production into information space for autonomous learning and training, ultimately achieving data analysis-based decision-making and execution for agricultural production processes [9]. Through online iteration between artificial simulation systems and real production systems, mutual promotion between scientific research and practical production systems is promoted, enabling "online connection" between laboratory models and algorithms and frontline command systems, thereby automating agricultural production and achieving the goal of cost reduction and efficiency improvement through green production. This agricultural intelligent system comprises four components according to the agricultural production process.

Intelligent Perception System—Establishing an Integrated Space-Air-Ground Data Collection System. This system comprehensively employs satellite remote sensing monitoring, UAV remote sensing monitoring, and ground station monitoring. Based on big data, cloud computing, and other key technologies, it accurately measures and collects "soil-water-atmosphere-biology" information related to agricultural production, achieving real-time dynamic monitoring covering all fields, entire processes, and full coverage of agricultural production. Due to the complex terrain in southern hilly and mountainous areas, ground monitoring—the most accurate method—faces numerous obstacles in practice. Therefore, low-altitude UAVs should be the primary means for precision monitoring in these regions.

Intelligent Communication System—Forming an Agricultural Dedicated Communication System Combining Ground Mobile Communication, Emergency Communication, and Satellite Communication. Agricultural production spans large geographic areas with remote locations, concentrated operation intensity, and low per-mu value density, requiring low-cost communication systems with wide-area coverage. Since information infrastructure in southern hilly and mountainous areas is already weak, large-scale construction of 4G and 5G communication base stations would be too costly. Consequently, satellite-network-based 6G communication represents the optimal choice for agricultural communication systems.

Intelligent Decision-Making System—Constructing a Supercomputing Center to Support Agricultural Intelligent Systems for Real-Time Rapid Processing of Agricultural Production Data. The computing center can process massive data in real time and support agricultural model training and intelligent algorithm solving. Simultaneously, it issues decision-making instructions to agricultural production sites connected to the system, providing support for production decisions in different plots. Given the diverse crop types

and complex planting structures in southern hilly and mountainous areas, the intelligent decision-making platform must continuously train and learn from transmitted data to gradually improve its decision-making capabilities.

Intelligent Operation System–Intelligent agricultural machinery performs high-quality operations while collecting data in real time [10], ultimately achieving data flow throughout the entire agricultural intelligent system. The complex environmental factors such as terrain and landforms in southern hilly and mountainous areas require personalized transformation and development of agricultural machinery based on local land conditions, crop characteristics, slope operation capabilities, and rock field operation capabilities.

3.4 Case Study: Shuicheng District Kiwi Industry Development and Intelligent Equipment Application

Shuicheng District is located in the core hinterland of Liupanshui City in western Guizhou Province, characterized by typical karst mountainous landforms with steep slopes, fragmented farmland, and severe rocky desertification and soil erosion. In 2017, Shuicheng was designated as a designated poverty alleviation county by the Chinese Academy of Sciences. Faced with a severe poverty alleviation situation, the Academy concentrated its scientific and technological strengths, leveraging comprehensive advantages to carry out targeted scientific and technological assistance based on local industrial development and technological needs. Currently, a modern agricultural industrial system has been established with kiwi as the leading industry, supplemented by edible fungi, potatoes, Rosa roxburghii, small yellow ginger, Chinese medicinal materials, mineral water, basalt fiber, and ecological fisheries, among others. Through technology-enabled industrial poverty alleviation, impoverished populations have increased income and escaped poverty [11].

Shuicheng District has approximately 120,000 mu of kiwi cultivation, primarily featuring the "Hongyang" and "Donghong" varieties, which account for over 95% of the city' s planting area. Kiwi field management activities such as bud rubbing, pollination, pruning, branch crushing, flower and fruit thinning, and harvesting are relatively concentrated, leading to concentrated labor demands and simultaneous product market entry, which easily creates seasonal labor shortages. This not only increases labor costs for the kiwi industry but also severely affects product pricing.

The Chinese Academy of Sciences has targeted the Shuicheng kiwi industry to develop an agricultural intelligent system based on full-factor simulation for fruit industries in mountainous and hilly areas, aiming to enhance agricultural production efficiency. To address labor shortages in kiwi production management, the Institute of Computing Technology of the Chinese Academy of Sciences has developed a new type of intelligent agricultural machine–the follow-up pruning and crushing machine, which achieves novel operation modes through advanced

intelligent technology (Figure 2 [Figure 2: see original paper]). This machine solves the problems of cumbersome pruning and crushing processes and time-consuming field return, enabling one-time crushing, in-situ field return, and increased soil nutrients.

The follow-up pruning and crushing machine features five characteristics: (1) **Mountainous adaptability**, using a tracked chassis with a 30-degree climbing capability, suitable for complex terrain and multiple operating conditions in karst mountainous areas. (2) **Intelligence**, employing multiple sensors and a self-developed control system to achieve automatic following, autonomous planning, handle remote control, and APP remote control functions. (3) **Modularity**, using a combination of standard intelligent chassis and operating components; by replacing operating components, the machine can be conveniently transformed into other intelligent mountainous agricultural machines, such as intelligent transport robots and intelligent rotary tillers. (4) **Clean energy**, with both traveling and operating components using pure electric drive, featuring low cost and no pollution, aligning with China' s clean energy technology trends. (5) **Platformization**, serving as the terminal execution component of the agricultural intelligent system, laying a solid foundation for implementing full-factor agricultural intelligent systems.

Compared with traditional fixed pruning and crushing machines, the follow-up machine reduces personnel walking distance and workload to about one-fifth, significantly decreasing kiwi pruning workload and improving work efficiency. Additionally, the machine can be extended to other fruit trees requiring pruning, such as peaches, pears, and apples, offering broad application prospects.

4. Development Recommendations for Science and Technology to Support Rural Revitalization in Southern China

4.1 Develop Top-Level Planning for Smart Villages in Coordination with Modern Urban Construction

Unbalanced and uncoordinated urban-rural development represents a prominent contradiction in China' s economic and social development. One core principle of the rural revitalization strategy is integrated urban-rural development and urban-rural modernization [12]. As General Secretary Xi Jinping stated in *Xi Jinping: The Governance of China* (Volume II): "We should open a new situation of integrated urban-rural development and modernization through rural revitalization." The report of the 20th National Congress of the Communist Party of China also emphasizes: "Adhere to prioritizing agricultural and rural development, and adhere to integrated urban-rural development." Therefore, in the new era, comprehensively promoting smart village construction should be led by government organizations. Based on existing agricultural and rural informatization planning and smart city top-level design, all levels of government, various enterprises, villages, and the public should be guided to actively participate. We should fully utilize new-generation information technologies such

as the Internet of Things, artificial intelligence, big data, and cloud computing to formulate construction specifications and standards, and make rural spatial planning and governance decisions based on big data backgrounds, thereby accurately and efficiently coordinating top-level planning design for smart villages and modern urban construction.

4.2 Strengthen Coordinated Transformation of Farmland, Machinery, and Agronomy to Promote Agricultural Mechanization and Intelligent Development

Promoting agricultural mechanization and intelligent development in southern hilly and mountainous areas must first address farmland mechanization adaptability [13]. Current farmland planning lacks differentiated detailed regulations for northern and southern geographic and environmental factors, leaving localities without standards during actual farmland transformation. It is recommended to combine the *National High-Standard Farmland Construction Plan (2021–2030)* with agricultural modernization development requirements, fully considering farmland, machinery, agronomy, and related elements. Based on north-south regional differences, national farmland mechanization standards should be formulated at the national level, clearly specifying optimal slopes, lengths, and widths for transformed plots while comprehensively considering operation conditions, transformation costs, and long-term benefits. Simultaneously, integration of agricultural machinery and agronomy should be considered to develop a complete mechanized production system for southern hilly and mountainous areas. Based on mechanization-adapted farmland, planting structures should be optimized, and technical routes for deep integration of machinery and agronomy should be developed. Demand lists for agricultural machinery and equipment in hilly and mountainous areas should be comprehensively compiled from varieties, industries, and links. Modular and serialized design methods should be employed to concentrate efforts on breaking through key technologies, forming a complete equipment system, and ultimately promoting mechanization and intelligent development of agriculture in southern hilly and mountainous areas.

4.3 Strengthen Rural Information Infrastructure and Establish a Unified Data System with Shared Functions

Advanced and complete information infrastructure is the foundation for building digital villages and an important information guarantee for developing smart agriculture. China' s smart agriculture infrastructure remains incomplete, with traditional communication methods unable to meet agricultural production demands. Therefore, accelerating rural information infrastructure construction must address the special network requirements of smart agriculture development. First, under the national new infrastructure strategy, accelerate the deployment of new infrastructure such as the Internet of Things and artificial intelligence. Promote co-construction and sharing of network infrastructure

in rural areas and agricultural production, create agricultural information perception and interconnection communication systems, and establish integrated space-air-ground observation systems. Second, focus on key directions of smart agriculture to advance satellite-network-based 6G communication construction, addressing critical issues such as wide-area field signal coverage, mobile communication, data transmission, and monitoring. Third, establish a unified national smart agriculture data system with shared functions at the national level. Open up data sharing channels for smart agriculture information resources to achieve integrated data utilization while ensuring data security to safeguard China' s smart agriculture data information [14]. With information infrastructure as the guarantee and massive data as the foundation, support the rapid development of China' s smart agriculture and inject technological momentum into rural revitalization.

4.4 Increase Policy Guidance and Talent Cultivation to Build a Professional and High-Quality Agricultural Workforce

High-quality agricultural talent represents the main force in smart agriculture development. The government should increase policy guidance and talent cultivation based on new changes in labor conditions and resource allocation in southern hilly and mountainous areas and new requirements for developing smart agriculture and building modern agriculture. First, increase policy support. Promote smart agriculture through comprehensive and multi-channel publicity, encourage university graduates, college student village officials, and agricultural scientific and technological talents to start businesses in rural areas, clarify corresponding entrepreneurship support policies, and attract rural migrant workers to return home for employment. Second, strengthen talent support. Strengthen collection of employment demand information from relevant entrepreneurial enterprises, provide information release and employment guidance services, and integrate technical skills, agricultural product marketing, agricultural management, and other agricultural scientific and technological talents into the local talent security system. Third, accelerate improvement of the new-type professional farmer training and education system. Unite agricultural machinery promotion service agencies, agricultural enterprises, and agricultural vocational colleges to conduct tiered and categorized training for new-type farmers around characteristic advantageous industries, building a high-quality farmer team with culture, technical understanding, business acumen, and management skills to provide solid human resource support for agricultural modernization.

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Note: Figure translations are in progress. See original paper for figures.