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Empowering Agriculture in Northeast China with Drones: The Low-Altitude Economy Driving the Smart Transformation of the Black Soil Region

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I. Introduction

As agricultural modernization accelerates, conventional agricultural production is facing multiple challenges, including labor shortages, low operational efficiency, resource waste, and environmental pressure. Against this background, technologies associated with the low-altitude economy, represented by unmanned aerial vehicles (UAVs), are being rapidly integrated into the entire agricultural production chain in Northeast China. They have become a key engine for developing new quality productive forces in agriculture[1-3].

1. The Core Logic of Drone-Empowered Agriculture in Northeast China: Overcoming the Efficiency Constraints of Conventional Agriculture

Agriculture in Northeast China benefits from large-scale land management and a strong foundation in mechanization, yet shortcomings in conventional production continue to constrain industrial upgrading. An aging agricultural workforce, inefficient manual operations, insufficient resource-use efficiency, and mounting ecological and environmental pressures have become major obstacles to agricultural modernization. The extensive application of drone technology directly addresses these problems. Its principal value lies in three dimensions—efficiency, precision, and ecological sustainability—and it is injecting new vitality into agriculture across Northeast China[2-3].

1.1 An Efficiency Revolution: The Shift from Labor-Intensive Work to Aerial Operations

In conventional agricultural production, crop protection, fertilization, and sowing depend heavily on manual labor. These operations are physically demanding and time-consuming, making it difficult to meet the strict scheduling requirements of large-scale farming. For example, applying basal fertilizer manually to 400 mu of paddy fields requires at least two days and repeated movement through muddy fields, whereas a crop-protection drone can complete the same area in only 2.5 hours, increasing efficiency by more than tenfold. In Fangzheng County, Heilongjiang Province, a single drone can perform crop-protection operations over 300–500 mu per day, which is 20–30 times the area covered by manual spraying. This substantially alleviates the labor shortages and high operating costs associated with large-scale cultivation[2-3].

1.2 A Breakthrough in Precision: Upgrading from Extensive Input Application to Data-Driven Operations

In conventional agricultural production, pesticide and fertilizer application often relies on experience, which can result in missed areas, repeated spraying, and excessive application. These problems waste resources and may also cause soil contamination and excessive residues in agricultural products. Drone systems equipped with BeiDou navigation, AI-based intelligent modeling, and multispectral sensing enable precise control of agricultural operations, ensuring that pesticides and fertilizers are applied where they are most needed[3-9].

In precision fertilization, Tailai County in Qiqihar, Heilongjiang Province, has introduced drones equipped with AI-based intelligent modeling systems. By integrating data on soil conditions, rice varieties, and crop nutrient requirements, the systems use algorithms to calculate the fertilizer demand of different plots and support demand-based application, thereby reducing fertilizer waste. Operational data from the Qingshan Branch of Beidahuang Agriculture Co., Ltd. show that drone-based fertilization reduces fertilizer use by 15% and water use by 90% compared with conventional manual application. GPS-guided route planning also eliminates missed and repeated application, improving fertilization quality[5,9].

Drones also demonstrate strong precision in pest and disease control. Shenyang used drones for the first time to release Trichogramma wasps for corn borer control. Each release device, approximately the size of a table-tennis ball, can release more than 5,000 wasps. Drones accurately distribute the devices along predefined routes, enabling targeted parasitism of corn borer eggs. Compared with the manual placement of wasp cards, this approach is more efficient and produces no pollution. It therefore achieves the objective of biological control through natural enemies and provides a practical pathway for reducing pesticide use[6].

1.3 Ecological Sustainability: A Transition from Resource Consumption to Green and Low-Carbon Production

In conventional agricultural production, excessive fertilizer and pesticide use can cause soil compaction and water pollution, while waste generated during manual operations creates additional environmental pressure. Precise drone operations reduce resource waste and environmental pollution at the source, supporting the green and low-carbon transition of agriculture in Northeast China and aligning with the central requirements of sustainable agricultural development.

Drone-based crop protection uses highly concentrated atomized spraying to produce fine, uniform droplets with a high adhesion rate, thereby reducing pesticide use. Practice in Landian Township, Zhuanghe, Dalian, shows that drone spraying can reduce chemical use by 30% and operating costs by more than 50%. It lowers farmers' production costs while reducing pesticide contamination of soil and water. Moreover, drone operations do not require workers to enter the fields, which prevents crop damage from trampling, protects the soil structure, and supports the sustainable use of the region's black soil[4,7].

In biological control, using drones to release natural enemies avoids the use of chemical pesticides, protects the quality and safety of agricultural products, and maintains ecological balance in farmland. At Qianfeng Farm of Beidahuang Group, fully biodegradable mulching technology is used in coordination with drone operations. This approach saves more than CNY 320 per mu in weed-control costs while addressing pollution from discarded plastic film. It combines cost reduction and efficiency gains with ecological protection and provides a representative model for the green development of agriculture in Northeast China[8].

2. A Comprehensive Overview of Agricultural Drone Applications in Northeast China: Multi-Scenario Deployment and an Emerging Industrial Ecosystem

With technological advances and policy support, drone applications in Northeast China have expanded from crop protection alone to the entire production chain, including fertilization, sowing, crop-growth monitoring, biological control, and agricultural-product transport. These applications cover grain crops, cash crops, and specialty agriculture, creating a multi-scenario, full-cycle smart-agriculture ecosystem. Different parts of Northeast China have developed differentiated application models suited to their local agricultural characteristics, making the region a national benchmark for agricultural drone use[1-3].

2.1 Major Grain-Producing Areas: Full Coverage of Key Operations to Strengthen Food Security

As a major grain-producing region in China, Northeast China has comprehensively integrated drones into the cultivation of rice, corn, soybeans, and other staple crops. Intelligent management throughout the production process, from sowing to harvesting, provides a solid foundation for stable and increased grain output.

In rice cultivation, drones are used in key operations such as field preparation and flooding, fertilization, crop protection, and seedling-growth monitoring. After more than 400,000 mu of rice at Yaluhe Farm of Beidahuang Group entered the tillering stage, growers widely used drones to apply liquid green-up fertilizer and insect-control agents. Large-scale aerial crop-protection operations provide uniform atomized spraying and substantially increase operating efficiency, helping rice seedlings recover and resume growth rapidly[10].

In corn cultivation, drone applications focus on the precision control of pests and diseases and on crop-growth monitoring. Shenyang piloted the use of drones to release Trichogramma wasps for corn borer control in Shenbei New Area and Xinmin, covering 50,000 mu. The precise distribution of biodegradable wasp-release devices enables biological control to be implemented at scale and offers a green solution for corn borer management. At Hongxing Farm of Beidahuang Group, drones equipped with multispectral cameras are used for AI-assisted field inspections. A combination of remote-sensing drones and AI algorithms automatically calculates seedling density and the number of missing seedlings, assesses crop emergence and growth across the fields, and provides data for refined field management. Farmers can therefore monitor seedling conditions promptly and adjust management measures with greater precision[6,11].

For fertilization, the Qingshan Branch of Beidahuang Agriculture Co., Ltd. deployed more than 200 drones to apply basal fertilizer to over 400,000 mu of paddy fields. Because drones are not constrained by cultivation patterns or local terrain, they can operate safely and efficiently. Precise route planning also reduces fertilizer waste and supports high and stable rice yields. These practices demonstrate that drones have become an important technological force for food security in the major grain-producing areas of Northeast China, facilitating the transition from high and stable output to high-quality, efficient production[5].

2.2 Specialty Agricultural Areas: Expanded Functions and New Drivers of Industrial Development

Beyond grain crops, specialty agriculture in Northeast China has become another important area for drone deployment. Taking advantage of its mountainous terrain and extensive marine area, Dalian has extended drone applications from crop protection to lifting and transport in fruit production, fisheries, and other sectors, creating new momentum for specialty agriculture.

Data from the Dalian Municipal Bureau of Agriculture and Rural Affairs show that the number of agricultural drones in the city has risen to more than 500 and that crop-protection services cover nearly 50% of the relevant area. New agricultural drones can sow seeds, apply fertilizer, and spray chemicals, while also functioning as lifting equipment with a maximum payload of 170 jin (approximately 85 kilograms). Once loading and unloading locations have been configured, the drones can fly automatically. This substantially reduces the cost of transporting fruit, aquatic products, and other goods and addresses logistical difficulties in mountain orchards and offshore aquaculture areas. This expansion in functionality transforms drones from field-operation tools into integrated agricultural service platforms and advances the mechanized and intelligent transformation of specialty agriculture[7].

2.3 Smart-Agriculture Demonstration Areas: Technological Integration and Innovation Leading Agricultural Modernization

Across Northeast China, large-scale operators such as Beidahuang Group are establishing smart-agriculture demonstration areas. They are promoting the deep integration of drone technology with big data, artificial intelligence, and the Internet of Things, creating a new smart-agriculture model based on big data, drones, and AI and setting a direction for agricultural modernization[1,12].

During spring rice cultivation, Tailai County in Qiqihar uses drones equipped with AI-based intelligent modeling systems for fertilization. By combining data on soil conditions, rice varieties, and nutrient requirements, the systems use algorithms to calculate the fertilizer needs of different plots and perform precise variable-rate fertilization. This represents a new model for intelligent spring farming. The integration of these technologies improves fertilization efficiency and shifts agricultural production from experience-driven to data-driven management, providing technical support for more refined agricultural operations[9].

Shenbei New Area in Shenyang is exploring an integrated development pathway combining digital agriculture with the low-altitude economy. In cooperation with drone manufacturers, the district uses drones, automatic steering systems, Internet of Things devices, and other intelligent equipment to collect and analyze data on soil moisture, water quality, weather, pests, and diseases, thereby building a smart farmland management system. Sensing systems carried by drones generate operational maps that support variable-rate crop protection and precision fertilization. This shifts farmland management from extensive practices to refined control and provides a model for the digital transformation of agriculture[1,12].

3. An Assessment of the Outcomes of Drone-Enabled Agricultural Upgrading in Northeast China: Data Demonstrating Accelerated Development

The extensive use of drones in agriculture across Northeast China has produced substantial economic, social, and ecological benefits. A range of quantitative results directly demonstrates the effectiveness of technological empowerment and confirms the strong role of the low-altitude economy in advancing new quality productive forces in agriculture[2-3].

3.1 Operational Efficiency: Exponential Improvement that Overcomes the Constraints of Large-Scale Production

Compared with manual work, drone operations achieve a qualitative leap in efficiency and remove a major constraint on large-scale agricultural production. Data from Fangzheng County, Heilongjiang Province, show that a single drone can perform crop-protection operations over 300–500 mu per day, 20–30 times the area covered by manual spraying. This greatly shortens operating cycles and alleviates labor shortages in large-scale cultivation. At the Qingshan Branch of Beidahuang Agriculture Co., Ltd., manually fertilizing 400 mu of paddy fields requires two days, whereas drones complete the work in only 2.5 hours, representing an efficiency increase of more than 19 times. Data from Landian Township in Zhuanghe, Dalian, show that manually applying pesticides to 100 mu requires four to five days, whereas a drone completes the operation in only one hour, increasing efficiency by more than one hundred times[3,7].

3.2 Cost Control: Reducing Costs in Two Dimensions and Increasing Farmers' Returns

Drone use substantially lowers agricultural production costs in terms of both direct operating expenses and resource inputs, thereby increasing farmers' returns. In Landian Township, Zhuanghe, Dalian, data show that drone-based pesticide application costs more than 50% less than manual application. Drone fertilization at the Qingshan Branch of Beidahuang Agriculture Co., Ltd. also produces substantial savings in labor and material inputs compared with conventional manual fertilization. Regarding resource costs, precision drone fertilization can reduce fertilizer use by 15%, precision spraying can reduce chemical use by 30%, and water use can be reduced by 90%. These outcomes considerably lower expenditure on fertilizers, pesticides, and water[5,7].

3.3 Resource Utilization: Precise Control Supporting Green and Sustainable Development

Precise drone operations improve resource-use efficiency, substantially reduce the waste of fertilizers, pesticides, and water, and promote the green and sustainable development of agriculture in Northeast China. Data from the Qingshan Branch of Beidahuang Agriculture Co., Ltd. show that drone fertilization can reduce fertilizer use by 15% and water use by 90%, preventing ineffective consumption through precise control. In Shenyang, drones release Trichogramma wasps to control corn borers, enabling precise placement and targeted pest management. The approach reduces chemical pesticide use, lowers the risk of pesticide residues, protects the farmland ecosystem, and provides an effective pathway for biological control[4-6].

Although Tianjin is located in North China, its smart-farmland management model is highly applicable to agricultural drone use in Northeast China. Its data show that field management combining big-data analysis with drone operations can reduce water use by more than 30% and fertilizer use by approximately 15%. These findings further confirm the considerable potential of precise drone operations for resource conservation and provide a quantitative reference for the green and sustainable development of agriculture in Northeast China. The black soil of Northeast China is a valuable arable-land resource, and drone technology provides technical support for protecting it and reducing soil pollution, helping agriculture achieve both ecological and economic benefits[9,13].

3.4 Yield Security: Refined Management Strengthening the Foundation for Abundant Grain Harvests

Refined drone operations provide strong support for abundant grain harvests. Precision fertilization, precision crop protection, and crop-growth monitoring improve crop development and contribute to stable increases in yield. Data from Tianjin show that smart field management supported by drones can consistently increase wheat yield per mu by 10%–20%, demonstrating the contribution of precision management to higher grain output. As a major grain-producing region, Northeast China has deployed drones at scale for rice, corn, soybeans, and other crops. By precisely managing fertilization, crop protection, crop growth, and other key operations, these applications improve crop quality, reduce losses from pests and diseases, and support national food security through more reliable yields[9].

4. Challenges and Policy Responses for Drone-Empowered Agriculture in Northeast China: Addressing Constraints to Secure Long-Term Development

Despite the substantial results achieved by agricultural drones in Northeast China, their large-scale adoption remains constrained by technology, cost, human resources, and policy. Sustained and deeper application requires these problems to be recognized and addressed through targeted measures so that the low-altitude economy can fully realize its potential to strengthen new quality productive forces in agriculture[3,14].

4.1 Existing Challenges: Multiple Constraints on Large-Scale Adoption

4.1.1 Limited Technical Adaptability in Complex Operating Environments

Northeast China has a vast agricultural area and diverse, complex terrain. Mountains, hills, wetlands, and other environments place higher demands on drone endurance, obstacle avoidance, and wind resistance. Some existing drones remain unstable in complex terrain and have limited endurance, making them unsuitable for large-scale, long-duration operations[3].

4.1.2 High Purchase and Maintenance Costs for Small and Medium-Sized Farmers

Despite policy subsidies, advanced agricultural drones remain expensive, with some high-end models costing more than CNY 40,000. This creates substantial pressure from the initial investment, particularly for small and medium-sized farmers. Maintenance is also costly because battery replacement, component repair, and technology upgrades require considerable expenditure. In addition, professional training is necessary for drone operation, further increasing farmers' costs[15].

4.1.3 A Shortage of Skilled Personnel and Insufficient Operational and Maintenance Capacity
Drone operation requires specialized knowledge and skills. Operators must understand not only flight control but also crop production, pest and disease management, and data analysis.
4.1.4 Incomplete Policies and Standards and Gaps in Regulation
Agricultural drones are an emerging field, and the relevant policies, regulations, industry standards, and supervisory systems are not yet fully developed. Unified standards are lacking for airspace-use approval procedures, flight-safety requirements, and operational qualifications. Differences in policy implementation among regions also expose drone operators to airspace restrictions and cumbersome approval procedures[14].
4.1.5 Insufficient Technological Integration and Limited Coordination within Smart Agriculture
Current agricultural drone applications in Northeast China are concentrated mainly in individual operations. Integration with big data, artificial intelligence, the Internet of Things, and other technologies remains insufficient, and a complete smart-agriculture industrial chain has yet to be established[1,3].

4.2 Development Measures: Targeted Policies to Activate New Momentum

4.2.1 Strengthen Technological Research and Improve Adaptability to Complex Environments
Research investment should be increased, and universities, research institutions, and drone manufacturers should be supported in joint technological development. Priority should be given to long-endurance drones with strong wind resistance and obstacle-avoidance capabilities that are suitable for the complex terrain of Northeast China, with a particular focus on improving endurance and operational stability[3].
4.2.2 Improve Subsidy Mechanisms and Reduce Costs for Small and Medium-Sized Farmers
Purchase-subsidy policies for agricultural drones should be further optimized by expanding coverage, raising subsidy levels, and introducing differentiated programs for small and medium-sized farmers to lower barriers to purchase. A drone maintenance service system should also be developed. Enterprises and cooperatives should be encouraged to provide professional repair, maintenance, and rental services, thereby reducing farmers' operating and maintenance costs[15].
4.2.3 Establish a Talent Development System and Build Professional Operations and Maintenance Teams
A comprehensive system for training personnel in agricultural drone applications should be established. Vocational colleges, training institutions, and agricultural extension departments should provide multi-level training in diverse formats, covering drone operation, maintenance, agricultural knowledge, and data analysis. Training should place greater emphasis on relevance and practical skills. Universities should also be encouraged to establish related programs and cultivate interdisciplinary professionals in agricultural drone applications[3].
4.2.4 Improve Policies and Regulations and Standardize Industry Development
The development of laws, regulations, industry standards, and supervisory rules for agricultural drones should be accelerated. These instruments should specify requirements for airspace use, flight safety, operator qualifications, and operational quality, while harmonizing regulatory standards and simplifying approval procedures. This will provide lawful access to airspace and a standardized institutional environment for drone operations[14].
4.2.5 Deepen Technological Integration and Build a Smart-Agriculture Ecosystem
The deep integration of drones with big data, artificial intelligence, the Internet of Things, and BeiDou navigation should be promoted to establish an integrated space-air-ground system for intelligent agricultural monitoring and operations. Agricultural data-sharing platforms should be created to remove barriers between data collected by drones and data on soil, weather, and crop growth. Interconnected data can then support intelligent decision-making throughout the agricultural production process[1,3].

5. Future Prospects: The Low-Altitude Economy Supporting a Smart Future for Agriculture in Northeast China

As the low-altitude economy becomes a national strategy, drone applications in agriculture across Northeast China will have broader opportunities for development. With continued technological breakthroughs, improved policies, and an increasingly mature industrial ecosystem, drones will become a core pillar of agricultural modernization in the region. They will drive the transition from mechanization to intelligent and digital production and provide lasting momentum for national food security and comprehensive rural revitalization[16].

Supported by the low-altitude economy, the vast black soil region of Northeast China will display even greater vitality. The sound of drone rotors will become a familiar presence over the fields, and the vision of smart agriculture will unfold across the region. Northeast China will thereby contribute its distinctive capabilities to national agricultural modernization and help build a secure and promising future for food security and high-quality agricultural development.

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