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Current Research Status and Future Prospects of Small Agricultural Machinery in Hilly Regions

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ABSTRACT

Hilly and mountainous regions constitute vital agricultural production bases in China; however, constrained by factors such as complex topography and fragmented land parcels, large-scale agricultural machinery often struggles to operate effectively, making small-scale agricultural machinery pivotal for achieving mechanization in these areas. This paper reviews the development history and research trends of small-scale agricultural machinery in hilly regions both domestically and internationally, focusing on analyzing the current state of research from perspectives such as powertrain systems, multi-functional operating implements, and intelligent technologies; it summarizes key bottlenecks—including insufficient reliability, limited adaptability, and low degree of intelligence—and explores future development trends such as lightweight design, new energy propulsion, intelligent control, and machine-friendly coordination, thereby providing a reference for the innovative R&D and widespread application of small-scale agricultural machinery equipment in China's hilly and mountainous regions.

KEYWORDS

Small-scale agricultural machinery; Agricultural mechanization; Intelligent agricultural machinery; Hilly ground

1. INTRODUCTION

In China, the cultivated land area in hilly and mountainous regions accounts for approximately one-third of the nation's total cultivated land area. These areas primarily cultivate economic crops such as rice, corn, tubers, tea, fruits, and traditional Chinese medicinal herbs, playing an irreplaceable role in ensuring national food security and supplying specialty agricultural products [1–2]. However, these regions commonly face challenges such as small plot sizes, significant elevation variations, and narrow field access roads; consequently, large and medium-sized agricultural machinery struggle to enter these fields, find it difficult to turn, and exhibit low operational efficiency, resulting in a comprehensive mechanization rate that is significantly lower than that in plain areas. Therefore, vigorously developing small-scale agricultural machinery adapted to hilly terrain has become an urgent necessity for addressing the gaps in agricultural mechanization and advancing rural revitalization [3].

"Small-scale agricultural machinery" generally refers to operating equipment featuring a matching power output of approximately 15 kW, a relatively light overall weight, and ease of relocation and field turning; such equipment includes microtractors, small harvesters, field management machines, single-track transporters, and mini-seeders, among others [4]. In recent years, driven by advancements in technologies such as materials science, power batteries, and sensors, small-scale

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agricultural machinery has been evolving from an extensive approach toward precision-oriented and intelligent systems [5].

2. DEMAND CHARACTERISTICS OF SMALL-SCALE AGRICULTURAL MACHINERY IN HILLY REGIONS

Agriculture in hilly and mountainous regions imposes specific requirements on machinery. First, due to steep terrain slopes, the machinery must possess excellent climbing capability, a stable center of gravity, and anti-tip-over design; typically, crawler-type mobility systems are employed, equipped with differential locks or stationary steering functions. Second, as field plots often exhibit irregular shapes and vary widely in size—some being large while others are small—the machinery requires compact overall dimensions, a small turning radius, and the ability to rapidly switch between different farming implements to achieve multi-purpose functionality. Third, given the wide variety of crops and differing agronomic standards, the machinery must be capable of flexible adjustments across various operations, such as ditching, ridge formation, sowing, plant protection, and harvesting. Fourth, in hilly areas, the rural workforce is severely aging; therefore, the machinery must be easy to operate and maintain, and its purchase cost should not be excessively high [3]. These requirements collectively define the R&D trajectory for small-scale agricultural machinery: lightweight construction, narrow width, high ground clearance, multi-purpose capability, and enhanced safety and comfort.

3. CURRENT RESEARCH STATUS AT HOME AND ABROAD

3.1. International Experience in the Development of Agricultural Mechanization in Hilly and Mountainous Regions

Japan and South Korea are typical hilly and mountainous agricultural nations characterized by small average cultivated land area per household and highly developed small-scale agricultural machinery industries. As early as the 1970s, Japan had fully adopted compact paddy field machinery, such as ride-on transplanters and semi-direct seeding combine harvesters; representative products include harvesters with power outputs ranging from 22 to 35 horsepower produced by Kubota and Yanmar, which have a width of only 1.3–1.7 meters and are well-suited for working small plots of land [6]. In contrast, South Korea has vigorously promoted "multi-purpose farm management machines" and hand-held tillage machines, where a single unit can carry more than ten types of tools, including rotary tillage, ridge formation, plastic film laying, and grass cutting. In Europe, Italy and Spain commonly employ narrow-purpose specialized tractors and self-propelled sprayers in hilly vineyards and orchards, with some models already equipped with GPS navigation and automatic row alignment functions. The common experience among these countries is that governments provide substantial subsidies for farmers purchasing machinery while simultaneously implementing "machine-friendly" farmland transformation initiatives—such as Japan's "Farm Improvement Project," which merges fragmented plots and widens mechanized farming paths to create favorable conditions for the efficient operation of small-scale agricultural machinery. These practices offer valuable lessons for China [7].

3.2. Research Progress on Small-scale Agricultural Machinery in China

In recent years, research institutes and enterprises in China have conducted extensive work in the field of small-scale agricultural machinery for hilly and mountainous areas, with research efforts focusing on the following aspects.

(1) Power train and Mobility System

Small agricultural machinery chassis serve as the foundation for achieving multi-functional operations; current research focuses primarily on lightweight crawler chassis and articulated four-wheel drive chassis. Teams from institutions such as South China Agricultural University and Sichuan Agricultural University have designed several types of rubber crawler chassis specifically for southern hilly rice fields, employing elevated walking systems to increase ground clearance and utilizing hydraulic continuously variable transmissions to enhance torque output during low-speed climbing. Some studies have incorporated multibody dynamics simulations to optimize the chassis's trench-crossing, climbing, and rollover resistance performance [8]. To address the issue of frequent turning required for small plots, differential steering and in-place turning technologies have matured, enabling the machinery to perform U-turns within a radius of less than 2 meters. Additionally, electric chassis have emerged as a new growth area, with several lithium-ion battery-powered miniature crawler transporters already available on the market—characterized by low noise levels and zero emissions, making them well-suited for operations in greenhouses and orchards [9].

(2) Light weighting and modularization of key construction machinery

In the field of tillage machinery, micro-tillers remain the most widely used small-scale power-driven equipment; research efforts in this area focus on the wear-resistant and drag-reducing design of rotary tiller blades, as well as improvements in their fatigue performance [10]. The new "miniature integrated rotary tiller and ridge-forming machine" can simultaneously perform soil fragmentation, leveling, and furrowing, and has been successfully applied in greenhouses and vegetable cultivation bases [11]. During the planting stage, precision sowing machines and air-suction small-seed sowing machines for crops such as corn and soybeans have been successively developed; these machines can adapt to various crops by simply replacing the seed distribution plate. Regarding harvesting machinery, small full-feed and semi-feed combine harvesters have already formed a complete product line in rice and wheat-producing regions, with feed rates typically ranging from 1.0 to 1.8 kg/s and overall widths controlled within 1.5 meters. In recent years, cutter-threshers and picking-and-threshing machines designed for hilly areas—such as coarse grains (jowar, sorghum, buckwheat) and oilseed crops (rapeseed, peanut)—have emerged as new research focuses, predominantly employing comb-type or segmented harvesting methods to reduce the impurity content [12–13]. It is noteworthy that the establishment of modular interface standards enables the same drive head to be rapidly attached to components such as rotary tillage, grass cutting, pesticide spraying, and furrowing, thereby significantly enhancing the annual utilization rate of the machinery [14].

(3) Intelligent and Information Technology

Smart small-scale agricultural machinery is still in its nascent stage but is developing rapidly. In terms of navigation, the integration of low-cost positioning terminals based on Beidou RTK with visual sensors has already enabled small crawler-type vehicles to autonomously traverse predefined paths within orchards for applications such as automated pesticide spraying or grass cutting. The unmanned small transplanting machine developed by South China Agricultural University utilizes a LiDAR system to achieve automatic steering and obstacle avoidance in field conditions [15]. Additionally, remote control and operation monitoring systems based on mobile apps have been implemented on certain field management machines, allowing users to monitor battery levels and operational status in real time. Addressing the characteristics of fragmented hillside plots with complex boundaries, some researchers have proposed algorithms for identifying field boundaries based on 3D point cloud maps, thereby improving the accuracy of path planning. Currently, the primary constraints hindering the advancement of intelligent agriculture remain cost factors and poor network signal coverage in hilly terrain [5].

(4) New energy power applications

Fuel-powered small agricultural machinery faces challenges such as significant vibration, severe pollution, and complex maintenance requirements; in contrast, electric small agricultural machinery has gained popularity due to their simple structure and excellent torque characteristics. Research efforts have focused on battery pack assembly and management for high-energy-density lithium-ion batteries, control strategies for high-efficiency permanent-magnet brushless motors, and lightweight system integration. Various universities and private enterprises have already developed prototypes of electric tracked transport vehicles and electric tea garden pruning machines, which can operate continuously for 4–6 hours on a single charge. However, battery lifespan, charging infrastructure, and purchase costs remain key bottlenecks hindering widespread adoption [16–17].

4. THE MAIN EXISTING ISSUES

Although research on small-scale agricultural machinery in China's hilly regions has made certain progress, it still faces multiple challenges. First, there is insufficient reliability and durability. Many small-scale agricultural machinery products are derived from micro-tiller technology; key components—such as transmission gears, chains, and bearings—are prone to wear or fracture under continuous heavy loads, resulting in a typical failure-free operating time of fewer than 500 hours for the entire machine. While imported models offer reliable performance, their high cost makes them unaffordable for farmers.

Second, the integration between agronomic practices and agricultural machinery remains weak. In hilly regions, crop diversity is high, and agronomic parameters such as row spacing, plot width, and trellis height vary significantly across different crops, with no unified standards. Most agricultural machinery adopts general-purpose designs, resulting in poor adaptability to row harvesting and low-loss picking operations, which leads to high loss rates and impedes their widespread adoption. There is a lack of machinery models specifically tailored for particular crops; for instance, excavators for traditional Chinese medicinal herbs and small potato harvesters in hilly areas still predominantly rely on imitations, leading to inconsistent operational quality.

Third, the level of intelligence remains relatively low, and cost challenges are particularly acute. Currently, agricultural machinery in hilly regions still relies predominantly on manual operation, requiring operators to walk alongside the machinery, which entails high labor intensity. For some models equipped with automatic navigation and electronic control systems, the cost of these additional features accounts for more than one-third of the total machine price, resulting in low purchase willingness among farmers. Furthermore, unstable 4G/5G signals in mountainous areas hinder remote monitoring and data transmission.

Fourth, the basic conditions of hilly farmland pose constraints. Most hilly plots have not undergone mechanization preparation; their mechanized farming access roads are narrow, and some lack entry slopes into the fields; in some cases, small agricultural machinery can only be transported manually into the fields, thereby increasing auxiliary time and accident risks. Consequently, the energy efficiency of agricultural machinery operations cannot be fully realized.

Fifth, the standardization and service systems are lagging behind. Small-scale agricultural machinery products vary widely in type and have small batch sizes; there is a lack of unified testing and evaluation standards, parts exhibit poor interchangeability, and there are few after-sales maintenance outlets—particularly in remote mountainous areas, where malfunctioning machinery often remains idle, thereby dampening farmers' enthusiasm for using such equipment.

5. DEVELOPMENT TRENDS AND RECOMMENDATIONS

Based on the aforementioned research status and existing challenges, small agricultural machinery in hilly regions will evolve toward the following directions: lightweight design and application of new materials. The use of new materials such as aluminum alloy, high-strength steel, and engineering plastics can reduce the overall weight of the machine by 15%–30%, thereby lowering power consumption and soil compaction. Topology-optimized structural designs will further enhance the specific strength of these machines.

The adoption of new energy hybrid and pure electric drive systems is becoming increasingly widespread. As battery costs decline and energy density improves, small electric agricultural machinery designed for full-day operations will expand their applications from transportation and plant protection to tillage and harvesting stages. Range-extending hybrid solutions can alleviate battery range anxiety while maintaining high operational efficiency over extended working periods.

Intelligent and unmanned operations: low-cost RTK, vision-based systems, and IMU-based multi-source fusion navigation will become standard configurations; small-scale agricultural machinery will be capable of autonomous path-following between ridges, adaptive row spacing adjustment, and emergency stopping upon detecting obstacles. The cluster-based collaborative unmanned farm model—where multiple small-scale agricultural machines work together to perform planting, management, and harvesting—is particularly well-suited for hilly and fragmented fields, and will significantly enhance human-machine efficiency.

Modular design, multi-functionality, and rapid attachment capabilities. The unified quick-change interface and power output standard will break down barriers between different manufacturers, enabling farmers to flexibly configure machinery functions and achieve "one machine, multiple tools" for year-round utilization. This approach will effectively reduce the total cost of purchasing machinery.

Collaboration among agricultural machinery, agronomy, and farmland management (machinizable transformation): The state continues to advance "machinizable" land consolidation initiatives in hilly and mountainous areas, by merging fragmented plots, constructing mechanized farming roads and vehicle access points, and aligning these efforts with the R&D standards for small-scale agricultural machinery. In the future, the design of small-scale agricultural machinery will be more closely coupled with local leading industries and cultivation models, with a focus on developing specialized small-scale operating equipment tailored for regional characteristics such as tea cultivation, traditional Chinese medicinal herbs, and forestry fruit production.

Innovation in policy and promotion mechanisms: It is recommended to increase cumulative subsidies for agricultural machinery purchases in hilly and mountainous areas, launch pilot programs for shared agricultural machinery leasing, and foster regional full-process mechanization service organizations to address the challenge of "being unable to afford or unable to properly operate" such machinery. Simultaneously, efforts should be made to accelerate the formulation of quality evaluation standards for small-scale agricultural machinery and to promote the healthy development of the industry.

6. CONCLUSION

Small-scale agricultural machinery in hilly regions serves as critical equipment for achieving full mechanization coverage across China's agricultural sector—representing the "last mile." Currently, China has accumulated substantial research achievements in areas such as chassis mobility, lightweight power systems, and multi-functional implements, while having preliminary explored pathways toward intelligent and electrified solutions. However, challenges such as low reliability, poor adaptability, high costs associated with intelligence integration, and underdeveloped rural infrastructure continue to hinder their large-scale adoption. In the future, with the deep integration of

new materials, new energy sources, and intelligent control technologies, alongside the simultaneous advancement of machine-friendly retrofitting efforts, small-scale agricultural machinery will continue to evolve toward lighter designs, electrification, unmanned operation, and modular configurations, thereby injecting strong momentum into the modernization of agriculture in hilly and mountainous regions.

REFERENCES

[1] Luo, X. (2011). Reflections on the development of agricultural mechanization in hilly and mountainous areas. Agricultural Science and Technology Extension, (2).

[2] Han, Y., Dong, H., Wu, H., et al. (2025). Current status and reflections on the development of agricultural mechanization in hilly and mountainous regions. Agricultural Engineering, 15(10).

[3] Wang, S., & Geng, L. (2016). Current status and countermeasures for agricultural mechanization development in hilly and mountainous regions. Agricultural Engineering, 6(05).

[4] Wei, X. (2025). Adaptability and development of small agricultural machinery in hilly and mountainous areas. China Agricultural Knowledge Repository, 21(04).

[5] Ren, B. (2026). Analysis of development trends for small-scale agricultural machinery in hilly and mountainous regions. Southern Agricultural Machinery, 57(08).

[6] Huang, X., Song, G., & Gao, X. (2023). Analysis of the current status and development of small-scale agricultural machinery in Japan. Modern Agricultural Equipment, 44(06).

[7] Zhang, Z., & Li, Q. (2019). Experiences in the development of agricultural mechanization in hilly and mountainous regions of Japan and South Korea. Agricultural Machinery Promotion Science & Technology, (08).

[8] He, L. (2021). Research on fully hydraulic crawler chassis for hilly and mountainous terrain. Sichuan Agricultural University.

[9] Li, J. (2024). Design and operation parameter optimization of a pure electric small rotary plow for protected greenhouse applications. Xihua University.

[10] Zhu, Y. (2025). Research on the structural design and fatigue performance of rotary tillage blades for hilly and mountainous regions. Guizhou Normal University.

[11] Yuan, Y., Ge, J., et al. (2023). Design of an electric crawler-type rotary tiller-and-soil-raising integrated machine for greenhouse applications. Hebei Agricultural Machinery, (15).

[12] Wang, B., Gao, Y., & Lu, H. (2024). Investigation of electric-drive high-efficiency precision sowing mechanization technology for hilly regions. Agricultural Equipment & Technology, (04).

[13] Wang, X., He, S., Qin, W., et al. (2025). Development of an air-assisted precision sowing device for rice field plot breeding. Research in Agricultural Mechanization, 47(06).

[14] Yang, T., Zhao, W., Xin, S., et al. (2022). Design and experimental study of a rapid switching device for agricultural machinery in hilly and mountainous areas. Agricultural Research in Arid Regions, 40(03).

[15] Li, Y. (2023). Research and experimental study of operation path planning methods for rice cultivation machinery in automated farms. South China Agricultural University.

[16] Zhao, G., & Guo, X. (2025). Design and simulation testing of a small-scale electric crawler-type rapeseed seed broadcasting machine. Southern Agriculture, 19(17).

[17] Yu, Y. (2025). Design and analysis of a tracked transport vehicle for hilly and mountain orchard areas. Chongqing Three Gorges University.