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Research Status and Trends of Maize Planters for Hilly and Mountainous Areas

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Abstract

Hilly and mountainous areas are important maize-producing regions in China. However, due to complex terrain, limited economic conditions, and a lack of suitable machinery, the mechanization level of maize sowing in these regions has long lagged behind that of plain areas, becoming a key bottleneck restricting industrial development. Focusing on maize seeders suitable for hilly and mountainous areas, this paper begins with the types of seed metering devices, summarizing mechanical types such as fluted roller, cell wheel, spoon wheel, and turntable structures, as well as typical representatives of pneumatic seed metering devices, and analyzes their working principles and applicable characteristics. On this basis, relevant research progress both domestively and internationally is reviewed: foreign countries started earlier and have continuously advanced in areas such as precision seeding, pneumatic metering, structural optimization, and electric drive; since the 1980s, China has developed various small-scale seeders—including hand-held, pedal-operated, self-propelled, and electromagnetic vibration types—for small plots and complex terrain, achieving certain progress in adaptability. However, from the perspective of practical application, current small-scale maize seeders still commonly suffer from insufficient reliability, poor adaptability, and weak versatility, with a notable shortage of specialized models suitable for hilly and mountainous areas. Considering actual agricultural production needs and technological development trends, future improvements in such seeders should focus on multi-function integration, intelligent control, and environmental sustainability to better accommodate the planting conditions and mechanization development requirements of hilly and mountainous regions.

Keywords

Hilly and mountainous areas, maize planter, mechanization.

1. INTRODUCTION

As one of the three major cereal crops in China, maize is cultivated across a wide range of areas, with a total planting area of 24.5 million hectares and an annual output stabilizing at approximately 127 million tons [1]. Currently, maize production in China has formed three major core producing areas, each with distinct distribution and varying shares of planting area. The first is the northern maize producing area, covering the three northeastern provinces, Inner Mongolia, Hebei, Shanxi, Tianjin, and Beijing, accounting for about 40% of the national total maize planting area. The second is the Huanghuai Plain maize producing area, mainly comprising Shandong, Henan, Jiangsu and other provinces, with a planting area accounting for approximately 25% of the national total. The third is the southwestern hilly maize producing

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area, involving regions such as Yunnan and Guizhou, where the planting area accounts for about 15% of the national total [2].

China is a typically mountainous country. Among its total land area of 9.6 million square kilometers, hilly and mountainous areas account for about 44%, a proportion nearly four times that of plain areas, and such terrain is mostly concentrated in the southern region of the country [3]. From the perspective of the current overall development of agricultural mechanization in China, the mechanization process in plain areas has progressed rapidly with a relatively high level, most having entered the intermediate stage of development. In contrast, the development of agricultural mechanization in hilly and mountainous areas is significantly lagging behind with a low level, most remaining in the initial stage. The gap between these regions and the plain areas is considerable, and the issue of regional imbalance in agricultural mechanization development has become increasingly prominent.

Influenced by a combination of factors such as economic conditions, geographical environment, and planting practices, the maize production model in hilly and mountainous areas remains relatively backward. In particular, the two core production links—planting and harvesting—suffer from a shortage of suitable small and medium-sized agricultural machinery, resulting in low production efficiency and planting profitability, which in turn dampens farmers' enthusiasm for maize cultivation. Given the current situation, improving the mechanization level of maize production in the hilly areas of southern China is of great significance for promoting the high-quality development of the maize industry and mobilizing farmers' enthusiasm for maize cultivation. Therefore, such efforts are necessary.

2. TYPES OF CORN SOWING TECHNOLOGY MACHINERY

In recent years, the process of promotion and application of precision and small-quantity seeding machinery as well as precision seeding machinery for intertilled crops has been continuously accelerated in China. The core component of a maize seeder lies in the configuration of the seed metering device. At present, the seed metering devices widely used in maize seeding operations in China are mainly divided into two types: mechanical and pneumatic seed metering devices.

2.1. Mechanical seeding arranger

The main types include fluted roller, cell wheel, spoon wheel, and turntable, among others. These seed metering devices share the common characteristics of simple structure and low manufacturing cost. However, they have relatively strict requirements regarding seed size specifications and exhibit a relatively narrow range of applicability when adapting to different varieties.

(1). Fluted roller seed metering device. When the fluted roller seed metering device is in operation, the fluted roller rotates. Seeds fill the seed box and the grooves of the roller by gravity, and are then carried out by the grooves of the roller, thereby completing the seeding operation. This type of seed metering device is classified as a semi-precision seeder, as shown in Figure 1.

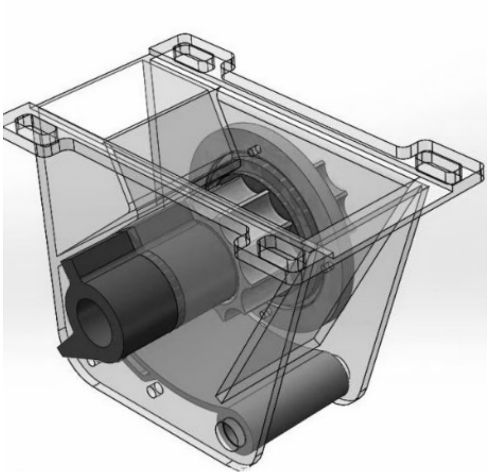

Figure 1. fluted roller seed metering device

(2). Cell wheel seed metering device. When the cell wheel seed metering device is in operation, seeds inside the seed box fall into the cells of the cell wheel by gravity. As the cell wheel rotates, a scraper removes excess seeds from the cells. The seeds remaining in the cells are then rotated along a seed guard plate to the designated position at the bottom, where they fall into the seed tube by gravity. To prevent seeds from becoming lodged in the cells, some cell wheel seed metering devices are equipped with a seed-pushing mechanism, also known as the forced-discharge cell wheel seed metering device. During operation, this mechanism forcibly pushes the maize seeds out from the inside of the cells. as shown in Figure 2.

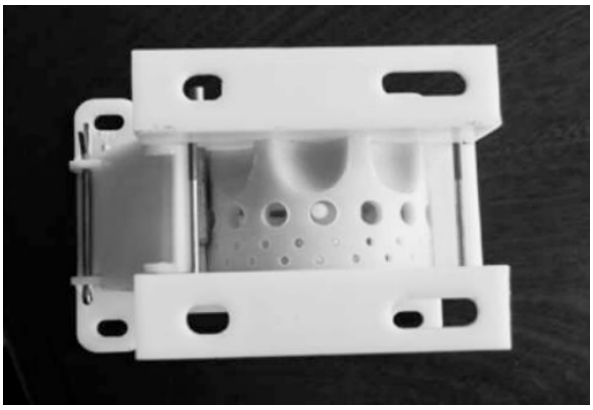

Figure 2. Cell wheel seed metering device

(3). Spoon wheel seed metering device. The working principle of the spoon wheel seed metering device is as follows: each spoon wheel unit on the disc can hold only one maize seed. The spoon wheel transports the maize seed into the groove of the seed guide wheel, while excess seeds fall off naturally under gravity. The seed guide wheel rotates synchronously with the spoon wheel. When it rotates to a specific position, the maize seed falls into the seed metering plate and is discharged, at which point the seeder completes the entire seeding operation process, as shown in Figure 3

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Figure 3. Spoon wheel seed metering device

(4). Turntable seed metering device. When the turntable seed metering device is in operation, the circular plate with holes rotates. Driven by the rotation of the plate, seeds enter the holes of the plate under the combined action of gravity and centrifugal force, and then rotate together with the plate. Excess seeds on the plate are completely removed by a scraper. As the plate continues to rotate, the seeds that have entered the holes are carried to a fixed position and then fall, completing the discharge process through the seed tube, as shown in Figure 4.

Figure 4. Turntable seed metering device

2.2. Pneumatic seed metering device.

The pneumatic seed metering device is generally driven by the power take-off of the tractor to operate the fan, thereby generating vacuum suction or air pressure. Under the action of such pneumatic force, seeds can adhere tightly to the surface of the orifices of the metering device, and the two key processes—seed filling and seed cleaning—are both accomplished by pneumatic force. This type of metering device mainly includes vacuum type, blow type, and air pressure type. Its prominent advantages are that it does not impose strict requirements on seed shape and size, results in a low seed damage rate, is suitable for high-speed seeding operations, and can be used in conjunction with large and medium-sized seeding machinery. At the same time, pneumatic seed metering devices also have certain disadvantages: their structure is relatively complex, and the requirements for manufacturing precision are more stringent.

(1). Vacuum-type seed metering device. The vacuum-type seed metering device operates by means of the suction generated by air vacuum. Its core component is the metering plate with suction holes. When the metering plate passes through the seed chamber, seeds are adsorbed onto the surface of the suction holes under the action of the pressure difference on both sides of the plate. As the metering plate continues to rotate, when the suction holes leave the end of the suction channel, the negative pressure state disappears, and the seeds fall by gravity into the furrow opened by the furrow opener, as shown in Figure 5.

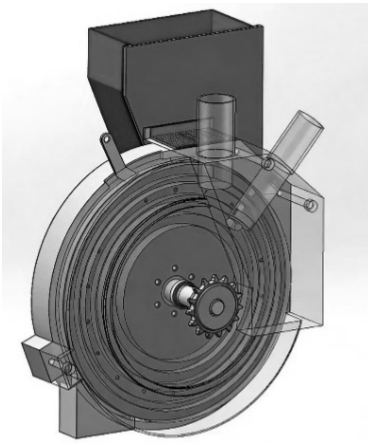

Figure 5. Vacuum-type seed metering device

(2). Blow-type seed metering device. The blow-type seed metering device is basically similar to the cell wheel seed metering device in terms of the seeding process, differing in that it uses airflow to remove excess seeds.

2.3. Summary of this chapter

Based on the above analysis, it can be seen that mechanical seed metering devices (including fluted roller, cell wheel, spoon wheel, and turntable types) have simple structures, low manufacturing costs, and low power requirements, offering certain advantages for promotion under the conditions of small plots and decentralized farming in hilly and mountainous areas. However, they impose strict requirements on seed size specifications, have a narrow range of applicable varieties, and are mostly classified as semi-precision or non-precision seeders, with inherent limitations in operational accuracy and stability. Pneumatic seed metering devices (such as vacuum-type and blow-type) exhibit stronger adaptability to seed shape and size, low seed damage rates, and high operating speeds, making them suitable for precision seeding requirements. Nevertheless, their complex structures, high manufacturing costs, and stringent requirements for supporting power and airtightness pose significant constraints on their promotion and application in the context of hilly and mountainous areas, where economic conditions are limited, plots are fragmented, and small-scale machinery predominates.

Thus, it is evident that the existing types of seed metering devices all have limitations to varying degrees in terms of applicability to hilly and mountainous areas: while mechanical seed metering devices offer relatively low costs, they lack sufficient precision and adaptability; pneumatic seed metering devices, despite their superior performance, are difficult to realize under conditions of miniaturization and low cost.

3. CURRENT STATUS OF MAIZE PLANTERS FOR HILLY AND MOUNTAINOUS AREAS

3.1. Current status of foreign research

Research on seeders in foreign countries began relatively early, and by the 1960s, precision seeders that are still in use today had already emerged [4]. The planting industry in Europe and the United States is mainly concentrated in vast plain areas. Based on this geographical characteristic, the degree of mechanized operation is relatively high, with widespread adoption of multi-beam towed large and medium-sized machines [5].

In 1989, to meet the demand for precision and small-quantity seeding of small-grain cereals, European scholar Gianni and his team successfully developed a vacuum-type precision metering device, marking a new stage of development for precision and small-quantity seeding of small-grain crops [6].

In 1991, Siebertz et al. developed a dibble-type precision seeder suitable for sowing a variety of cereals. This machine features hollow, quadrangular pyramid-shaped dibble shovels mounted on a bidirectionally inclined disc. During operation, the trajectory of the dibble shovel opens holes in the soil, and the seeds discharged from the metering device fall directly into the holes through the dibble shovel [7].

In 2004, Barut et al. investigated the effects of different working parameters on the seed-holding performance of a single metering device for a vacuum-type seeder. The study considered factors such as the shape of the metering hole, peripheral speed, vacuum degree, hole area of the metering plate, and thousand-seed weight, and data processing was completed using analysis of variance and MSTAT-C statistical software [8].

In 2016, Japan's Yazaki SYV electric seeder was designed specifically for small vegetable seeds. The operation process generates no exhaust emissions, and it is powered by an electric motor, making it an environmentally friendly model. Its seeding component has a grooved-wheel exchange structure, with a continuous operation time of 3.5 hours per charge and a charging time of 4 to 5 hours [9].

Figure 6. SYV electric seeder

In 2018, Minfeng J et al. conducted research on structural optimization for the grooved roller metering device of a wheat drill. By changing the grooved wheel opening method, adding a "7"-shaped comb brush installation device, and adopting a combined grooved wheel structure, they addressed the issue of inconsistent opening adjustment, achieved precise positioning of the comb brush installation, enabled fine adjustment of the seeding gap between the grooved wheel and the comb brush, and facilitated manual replacement of the grooved wheel, thereby improving the applicability of the metering device [10].

In 2022, Tabal RE et al. developed a single-row push-type plot seeder for field breeding trials, equipped with a mechatronic seed supply device capable of achieving efficient seeding for different plots. Through field experiments and cost analysis comparing the maize plot seeder with two other seeders, the operational performance and economic feasibility of the equipment were verified [11].

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3.2. Current status of domestic research

The research and development of small-scale seeders in China began in the 1980s. After decades of development, significant progress has been made in both technology and production in this field. Important breakthroughs have been achieved in design. Traditional seeders, due to their heavy weight and complicated operation, were difficult to adapt to seeding operations in hilly, mountainous, and small-plot areas. In contrast, the small-scale seeders developed in China have been specifically optimized in this regard, with significant improvements in overall machine weight and operational convenience. These enhancements have not only effectively improved seeding efficiency but also enhanced adaptability to complex operating environments.

In 1999, Zheng Yucai et al. designed a handheld precision hill seeder. This device features a compact structure and is portable and easy to use. It operates reliably under both sandy and cohesive soil conditions, offering a wide range of applicability. It can complete four procedures—film cutting, film lifting, seeding, and soil covering—in a single pass [12].

In 2001, Wei Hong'an et al. developed a vertical insertion film mulching hill seeder for wheat. Based on the principle of a parallel four-bar linkage, this machine enabled the duckbill hole former to achieve vertical seed receiving, vertical insertion, and vertical emergence during soil penetration. Meanwhile, through the use of ground wheel transmission, it ensured that the duckbill experienced almost no horizontal displacement after being inserted into the soil. Experimental results showed that the hill seeder had a reasonable structural design, a high qualified rate of seeds per hill, and featured characteristics such as no missed hills, no clogging, no film lifting, and convenient soil covering [13].

In 2013, Xu Liang et al. designed and studied the 2BFQ-2 series grain seeder, which could be used in conjunction with walking tractors and was suitable for sowing various grains. The machine featured a reliable structure and convenient operation, primarily serving planting production in hilly areas of China [14].

Figure 7. 2BFQ-2 maize planter

In 2015, Zhao Jinji et al. developed the 2BJ-1 hand-push precision maize seeder, designed to meet the operational needs of small plots in hilly and mountainous areas without the need for external power traction. The machine adopted a disc-type structure. When pushed manually to move forward on the ground, the metering device, controlled by a ratchet wheel, delivered seeds into the seed bed through a duckbill opener. Experimental results indicated that its seeding accuracy met the precision standards specified for maize precision seeders [15].

In 2016, Li Yupeng and colleagues developed a small-scale electromagnetic vibration wheat seeder to address common issues in wheat seeders on the market, such as low operational efficiency, high energy consumption, and high purchase costs. The study conducted finite element analysis on key components including the furrow opener and soil coverer, and carried out field seeding experiments. The results showed that compared with traditional wheat

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seeders, this model offered advantages such as higher operational efficiency, better seeding quality, and lower energy consumption [16][17].

In 2016, Cao Huipeng developed a 2ZBF-2 self-propelled electric small-scale seeder. This model adopted a self-propelled electric form, reducing environmental pollution during operation and better meeting the seeding needs of hilly terrain [18]. In the same year, Zhang Yaxin et al. developed a pedal-operated maize seeder. This model was easy to operate; during operation, the operator stepped onto the pedal with both feet, driving the seeding mechanism through pedal force to achieve automatic seeding, effectively improving seeding efficiency under complex farmland conditions in hilly areas [19].

Figure 8. 2ZBF-2 self-propelled electric small-scale seeder

In 2017, Lyu Peng et al., addressing the difficulties of towed seed rope direct seeders in adapting to small-plot operations, as well as the reliance on manual labor, high labor intensity, and low operational efficiency of hand-pushed seed rope direct seeders, designed a hand-operated rice seed rope direct seeder by modifying the power source of the original prototype and optimizing key components. This model was suitable for small-plot operations and could complete multiple processes in one pass, including rotary tillage, furrow opening, seed rope laying, soil covering, and pressing [20].

In 2022, Yuan Xinyu et al., responding to the actual needs of ordinary farmers in small-scale planting scenarios, designed a precision sorghum seeder suitable for small-area plots. This machine used a small tractor as the towing power, and the working components—including the frame, furrow opener, soil covering and pressing device, fan, and generator—were appropriately selected and designed. Experimental results showed that all indicators met the agronomic requirements for sorghum sowing, effectively improving the seeding precision of small-scale sorghum cultivation in China while reducing operational labor intensity [21].

In 2023, Gu Zhipeng et al. designed and developed a small-scale seeder jointly controlled by a PLC, and conducted testing and analysis on its seeding precision and detection control system. The results indicated that the miss-seeding rate and reseeding rate of this model were stable, and this control technology contributed to improving the seeding quality of small-scale seeders [22].

3.3. Implications of Research on Maize Planters for Hilly and Mountainous Areas

Based on the domestic and international research progress presented above, it can be seen that foreign seeder technology started earlier and has accumulated substantial achievements in precision seeding, pneumatic metering, structural optimization, and electric drive. Against the backdrop of large-scale farming in vast plain areas, the technological development in Europe and the United States is characterized by large scale, high efficiency, and intelligence. For example, Barut et al.'s in-depth study on the operating parameters of vacuum-type seed

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metering devices, as well as MinfengJ et al.'s structural optimization of fluted roller metering devices, provide important technical references for improving seeding precision and operational stability. Japan's Yazaki SYV electric seeder, powered by an electric motor with zero exhaust emissions, reflects a development concept that combines environmental protection, energy efficiency, and miniaturization, offering direct reference value for small-plot operations in hilly and mountainous areas of China.

Since the 1980s, China has continuously carried out the development of various small-scale seeders tailored to the characteristics of small plots, complex terrain, and limited economic conditions in hilly and mountainous areas. In terms of structural innovation, handheld precision hill seeders and vertical insertion hill seeders have achieved multi-process integrated operations. In terms of power forms, models such as pedal-operated, self-propelled, and electromagnetic vibration seeders have emerged, effectively reducing labor intensity. In terms of technological upgrading, recent explorations in the application of technologies such as PLC joint control and electric drive in small and micro seeders have accumulated valuable experience for improving seeding precision and intelligence. Overall, domestic research has made significant progress in simplification, operational convenience, and adaptability to hilly and mountainous areas, resulting in a relatively rich accumulation of technology.

A comprehensive review of domestic and international research reveals that foreign technologies provide advanced concepts and technical pathways for the development of maize seeders in China's hilly and mountainous areas. In particular, research achievements in precision seeding, pneumatic metering, electric drive, and structural optimization can offer guidance for enhancing the performance of small-scale seeders in China. Domestic research, on the other hand, has accumulated practical experience in miniaturization, low cost, and adaptation to specific scenarios, initially forming a technological system suited to the characteristics of hilly and mountainous areas. However, from the perspective of practical application, existing small-scale seeders still have deficiencies in reliability, adaptability, and versatility, and there remains a shortage of specialized models suitable for operation in hilly and mountainous areas. In the future, it will be necessary to build upon the absorption of advanced foreign technologies while focusing on the actual production conditions of domestic hilly and mountainous areas to address the aforementioned issues.

4. CURRENT ISSUES

From the perspective of the current production and application status of maize seeders in China, there are a relatively large number of manufacturing enterprises, with certain differences in product specifications. In terms of machine types, they cover different specifications such as large, medium, and small sizes, as well as various operation forms including single-row, double-row, and multi-row configurations. However, in actual use, small-scale maize seeders still face certain problems.

4.1. Poor reliability

Small-scale maize seeders in China exhibit prominent issues in operational stability and component durability. The incidence of malfunctions during use is relatively high, particularly under poor operating conditions, where problems such as seed jamming, missed seeding, and transmission failure frequently occur, thereby affecting seeding quality and operational efficiency..

4.2. Poor adaptability

Small-scale maize seeders in China also suffer from insufficient adaptability, making them susceptible to soil conditions and external environmental factors. When soil moisture is high, field conditions are poor, or there is an excessive amount of root stubble residues, the seeder is

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prone to blockage of the seeding holes during operation, preventing normal seed drop. At the same time, issues such as soil accumulation and grass entanglement frequently occur, leading to row interruptions and missed seeding.

4.3. Poor universality

Currently, most small-scale seeders on the market have relatively high requirements for the uniformity of maize seed size; otherwise, seeding quality may be compromised. In addition, due to differences in kernel specifications among varieties, the corresponding seed metering components need to be replaced. These factors, to some extent, limit the applicability of the seeders, resulting in poor versatility.

4.4. Shortage of Maize Planters Suitable for Hilly and Mountainous Areas

Insufficient investment in the research and development of new machinery and technologies in the field of agricultural mechanization for mountainous areas has resulted in a limited number and narrow variety of high-performance maize planters suitable for mountain terrain, making it difficult to meet the actual demands of characteristic agricultural production in hilly and mountainous regions.

5. IMPROVEMENT STRATEGIES AND DEVELOPMENT TRENDS

In response to the aforementioned issues of poor reliability, poor adaptability, poor versatility, and the shortage of specialized models for maize planters in hilly and mountainous areas, and in consideration of actual agricultural production needs and technological development trends, future improvements for such planters should be pursued in the following directions.

5.1. Enhancing Versatility: Development of Multi-purpose Seeders

To address the issue of poor versatility, this can be resolved by developing multi-purpose seeders. On the one hand, based on the completion of seeding operations, by equipping or replacing relevant components, multiple functions such as rotary tillage, furrow opening, ridging, intertillage, earthing up, and fertilizing can be expanded. The implements configured should exhibit stable performance and be easy to assemble and disassemble. On the other hand, optimizing the structural design of the seed metering device enhances its adaptability to different crops and varieties, reducing the frequency of frequent adjustments to seeding components when changing varieties, thereby achieving high efficiency, multi-functionality, and the goal of multi-purpose use of a single machine.

5.2. Improving Reliability: Introduction of Intelligent Control Technology

To address the issue of poor reliability, improvements can be made through the introduction of intelligent control technology. By constructing an intelligent control system, real-time monitoring of seeding quantity and operational quality can be achieved, endowing the seeder with intelligent detection and judgment capabilities to promptly identify abnormal situations such as missed seeding and seed jamming and respond accordingly. By incorporating actuators and feedback circuits, functions such as automatic plant spacing adjustment and traveling speed control can be realized, reducing the impact of human operational errors and mechanical failures on seeding quality, thereby enhancing the operational reliability of the machine.

5.3. Improving Adaptability: Development of Specialized Seeding Machinery

To address the issues of poor adaptability and the shortage of specialized models, efforts should be made from two aspects. First, emphasis should be placed on lightweight design and anti-blocking structural design to improve the passability and operational stability of seeders under complex field conditions such as high soil moisture and abundant root stubble residues, thereby reducing the occurrence of soil accumulation, grass entanglement, row interruption,

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and missed seeding. Second, efforts should be directed toward the development of electrically driven, low-emission environmentally friendly seeding machinery to reduce environmental pollution during operation. At the same time, research and development of specialized models tailored to the specific terrain and agronomic requirements of hilly and mountainous areas should be strengthened to address the current situation of limited model variety and narrow selection.

As agricultural cultivation gradually progresses toward intensification and regionalization, agricultural machinery in areas with higher levels of mechanization in northern and eastern China is evolving toward larger scale, specialization, and intensification. In contrast, due to geographical constraints in the hilly areas of southern China, it is difficult to adopt large-scale equipment for supporting agricultural machinery. Therefore, agricultural machinery will present a pattern of coexistence between large-scale and small-scale equipment. For maize seeders used in hilly and mountainous areas, multi-purpose integration, intelligent control, and environmental sustainability will be the main directions for future development.

6. EPILOGUE

In summary, it is of great significance to conduct research on maize seeders to promote the development of agricultural production and improve the efficiency of maize seeding operations. Based on a review of the current research status of maize seeders both domestically and internationally, this paper presents an outlook on their future development directions. By accelerating the promotion and application of precision seeding equipment, enhancing the level of simulation analysis technology, and deepening the analysis of actual agricultural needs, it is expected to drive continuous progress in agricultural machinery on the basis of existing research and further improve agricultural production efficiency.

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