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Opportunities and Challenges for Field Experiment Equipment

Shuqi Shang,
Ph.D., professor,
e-mail: sqingnong@126.com;

Jiasheng Wang,
Ph.D., professor,
e-mail: jiasheng0813@163.com

College of Mechanical and Electrical Engineering, Qingdao Agricultural University, Qingdao, People's Republic of China

Abstract. Modern seed industry development could contribute up to 40 percent to increase agricultural production and efficiency. Mechanization of field experiments is an important means to improve the efficiency and precision of field breeding experiments. There is a big gap in the mechanization level and development of field experiments in different countries of the world. The International Association on Mechanization of Field Experiments established in 1964 has played a great role in promoting the development of field experiment mechanization in the world. At present, the advanced field experiment equipment is mainly concentrated in international manufacturers such as Wintersteiger in Austria, Almaco in the United States, Haldrup and Zürn in Germany. As a great agricultural country, China's demand for rice and maize seeds, the major food crops in the last 10 years, is about 250 million kilograms and 1.15 billion kilograms, respectively. A large amount of demand for seeds prompted China's field experiment mechanization that has made great progress. The research team of Qingdao Agricultural University has developed 16 types of new plot planters and plot harvesters which have been popularized and applied in China. But different crops, planting patterns and regional characteristics put forward higher requirements for adaptability of field experiment equipment. The precision of the seeder, the cleaning performance of the seeding and harvesting equipment and the intelligent technology of the equipment need to be further improved. In future development, more attention should be paid to the integration of modern information technology and intelligent technology into field test equipment, to improve operational efficiency and accuracy.
Keywords: field test equipment, mechanization of field experiments, intelligent technology, operation efficiency and accuracy.

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Возможности и проблемы экспериментального полевого оборудования

Шуци Шан,
Ph.D., профессор, e-mail: sqingnong@126.com;

Цзяшэн Ван,
Ph.D., профессор, e-mail: jiasheng0813@163.com

Колледж машиностроения и электротехники, Циндаоский Сельскохозяйственный университет, Циндао, Китайская Народная Республика

Реферат. Развитие современной семеноводческой отрасли может способствовать увеличению сельскохозяйственного производства и повышению эффективности до 40 процентов. Механизация полевых экспериментов стала важным средством улучшения производительности и точности результатов в селекции. Существует большой разрыв в уровне механизации и развития полевых экспериментов в разных странах мира. Международная Ассоциация по механизации полевых экспериментов, созданная в 1964 году, сыграла большую роль в содействии развитию механизации полевых экспериментов в мире. В настоящее время передовое оборудование для полевых экспериментов в основном сосредоточено у международных производителей, таких как *Wintersteiger* в Австрии, *Almaco* в США, *Haldrup* и *Zürn* в Германии. В Китае хорошо развито аграрное производство. Спрос на основные продовольственные культуры в стране за последние 10 лет составляет: на семена риса около 250 миллионов килограммов и на семена кукурузы 1,15 миллиарда килограммов. Большой спрос

на семена способствовал значительному прогрессу в механизации полевых экспериментов в Китае. Исследовательская группа Сельскохозяйственного университета Циндао разработала 16 типов новых сеялок и комбайнов, которые широко применяются в Китае. Но большое разнообразие культур, схем посадки, а также региональные особенности обусловливают более высокие требования к адаптации полевого экспериментального оборудования. Необходимо и дальше работать над улучшением точности посева, повышением эффективности очистки посевного и уборочного оборудования, а также развитием интеллектуальных технологий. Для повышения эффективности и точности работы следует уделять больше внимания интеграции современных информационных и интеллектуальных технологий при создании оборудования для полевых испытаний.

Ключевые слова: полевое испытательное оборудование, механизация полевых экспериментов, интеллектуальные технологии, эффективность и точность работы.

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The seed industry of a country is a national strategic industry, a basic core industry, and the source of national food security. The development of the modern seed industry is an internal factor to ensure an increase in grain production, and the contribution rate to agricultural production and efficiency has reached 40% [1]. Before the new seed varieties are put into the market and planted in large areas, complex plot breeding field experiments are needed, covering many aspects such as cultivation and harvest, field plant protection and seed treatment.

The application of field experiment mechanization can effectively improve the efficiency and precision of field experiments, and shorten the plant breeding cycle. The research of field experiment machinery began in the 1930s. In 1935, the world's first batch single row grain plot seeder was invented by Canadian breeding scientist H.J. Kemp [2, 3]. In 1940, the Canadian Craftsmen Machinery Company began to produce an aluminium cone batch short row plot metering device. In 1949, professor Grafius of South Dakota State University developed the first weighing four-row plot seeder. The milestone of field experiment mechanization development is a series of Oyjord plot seeders invented and put into production by Norwegian scientist professor Egil Ojord from 1958 to 1971, and the establishment of the International Association on Mechanization of Field Experiments organized by him in 1964 [4, 5]. Oyjord plot seeders are widely used in Europe, Asia, Africa, America and many other countries [6].

The development of mechanization of field breeding in China began in the 1980s. In particular, with the help of Professor Egil Oyjord, the first Oyjord plot seeder was manufactured in China in 1994. After that, many kinds of plot seeding equipment were developed and controlled by local test stations in China, but the operation standards and performance of domestic planting machinery were uneven. In the past decade, the R&D team of Qingdao Agricultural University, relying on the platform advantages of the International Association on Mechanization of Field Experiments (IAMFE), has made remarkable achievements in the field of breeding instrument research and development field after years of research and accumulation [7].

International opportunities for field experimental equipment

The IAMFE has 11 national branches around the world and has established contacts with more than 130 countries. The main goal of the organization is to help agronomists and breeders from all over the world to understand the new field breeding machinery and related technologies and improve the efficiency and accuracy of field trials [8]. Up to now, IAMFE has hosted 15 sessions of international conferences and equipment exhibitions on mechanization of Field Experiments and 7 regional conferences. It plays an important role in the development and application of mechanization of field breeding experiments in the world [9].

At present, the international well-known international manufacturers of field experiment equipment include Wintersteiger from Austria, Almaco from the United States and Haldrup and Zürn from Germany [10-12]. Wintersteiger is one of the earliest and most famous field test equipment manufacturers in the world. The equipment produced by Wintersteiger covers the whole process of plant breeding and research from sowing to harvesting. The products include a plot combine and a breeding combine, a plot feed harvester, a plot planter, software solutions for data management, as well as fertilization and crop protection equipment and laboratory equipment [13, 14]. Almaco is another leading field experiment equipment manufacturer in the world. It produces a full range of equipment and instruments, covering the whole process of plant breeding [15]. Although Haldrup and Zürn are small in scale, their products have distinctive characteristics and occupy a certain niche in many countries' markets [16].

Strategy and policy of seed industry in China

China is a big agricultural country, and the demand for seeds is very large. Since 2010, China's main grain crops, rice and corn seed demand has been about 250 mil-

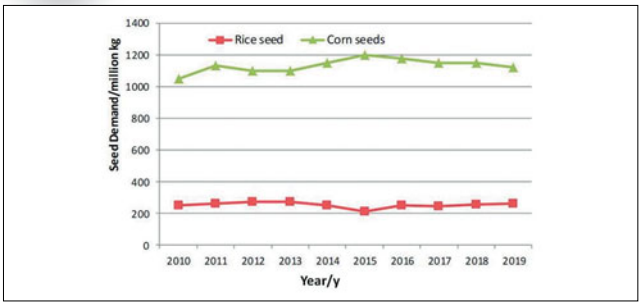

Fig. 1. Rice and corn seed demand in recent 10 years in China

lion kg and 1.15 billion kg, respectively (*Fig. 1*). At present, the seed breeding stage in China is still dominated by manual operation, with low production efficiency and high labor cost, which leads to low economic benefits of the seed industry, and it is urgent to improve the level of seed mechanization. From 2010 to 2015, the number of seed enterprises with valid business licenses decreased from 8700 to 4660. The concentration of the domestic seed industry has been effectively improved, which is conducive to the emergence of large seed enterprises. With the emergence of large seed companies, the requirements for breeding machinery are getting higher and higher [17].

On July 8, 2000, China government promulgated the seed law of the People's Republic of China to protect the safety of the seed industry in China, encourage the use of efficient and safe seed production machinery, and bring the advanced and applicable manufacturing equipment into the scope of agricultural machinery purchase subsidies. China attaches great importance to the sound and rapid development of field experiment machinery. The «National Development Plan for Modern Crop Seed Industry (2012-2020)» issued by the China State Council clearly points out that one of the development goals of China's crop seed industry is to explore a number of gene resources with outstanding target traits and excellent comprehensive traits and cultivate a number of new varieties with high yield, high quality, multi-resistance, wide adaptability and adaptability to mechanized operation and facility cultivation.

Development and innovation of field experiment mechanization

With the support and guide of IAMFE, a research team on the machinery of field experiments led by prof. Shang Shuqi was built to study plant breeding machinery. Two national projects (2010-2015 and 2016-2020) on plant breeding mechanization were supported by China government. Four plant breeding field bases over 100 ha were built in Shandong Province and Jiangsu Province to carry the field experiments for the plot machine. The research team cooperated with six Chinese manufacturers to develop the equipment for field experiments together (*Fig. 3*). According to the needs and requirements in breeding machinery in China, the development program plans were determined after careful discussion and analysis. Based on the production model of crop variety breeding in China, the key problems to be solved in the mechanization of breeding equipment were analyzed. Through innovative research and technical breakthrough, technical problems such as low precision, difficulty to clearly and easily mix in the process of planting and harvesting in the plot were solved [18-21]. As a result of 10 years' research work, 16 new types of plot seeders and plot harvesters were developed by the research team. The operating crops include wheat, corn, rice, peanuts and vegetables (*Fig. 2*).

Fig. 2. QAU Peanut Combine Harvester

Massive experiments were conducted in the field by using these prototypes. The experimental results show the plot machines' performance can meet the requirements for the plant breeding field experiments in China. Some research prototypes have been made a batch by Chinese manufacturers and launched into the Chinese market (*Fig. 3*).

Fig. 3. Plot seeders developed by QAU in recent years

Diversity of crop planting patterns

The crops, that need breeding, include wheat, corn, rice, rape, vegetables, etc. each crop has its own breeding mode and requirements. Even for one crop, there are differences in planting patterns in different regions in China because of soil, water source, light, seed size, planting habits and other factors. The common planting methods include flat planting, ridge planting and border planting. There are some differences in the row spacing, ridge spacing and plant spacing in different regions (*Fig. 4*). To meet the specific requirements for breeding contrast experiments, the plot field experimental mode includes ear row, plant row, plot evaluation and so on.

Fig. 4. QAU Carrot Combine Harvester

Challenges for the technology of field experimental equipment

At present, there are significant technical problems in the mechanization of field breeding in China. The main technical problems are listed as follows:

1. Technology of quantitative seed separation for small size seeds. The technology directly affects the uniformity of seed metering.

2. Seed cleaning technology of a plot seeder. When a plot is sown and the planter goes to the next one, there must be no residual seeds in the planter, otherwise, it will cause mixed planting.

3. Seed cleaning technology in a plot combine harvester. There are the same requirements as for the plot seeder, i.e. when a plot harvesting is finished, the seeds in the harvester must be cleaned up. The parts to be cleaned include the header, disengagement device, cleaning device and conveying channel of the harvester.

4. Many technologies, especially automation and intelligent technology are not mature, some functional links still need to be completed manually, decreasing the field test accuracy and efficiency.

5. Automatic yield measurement technology of a plot combine harvester. The key problem to be solved is the sensing technology of real-time and rapid measurement of seed moisture content.

5. Prospect and suggestions on the future development of experimental equipment.

Problems in the mechanization of breeding

The requirements for crop breeding in China are complex and diverse, there are few effective solutions, and the overall level is still relatively low. At present, there is an urgent demand for field test machinery and equipment, there is an insufficient research investment and no finalized product. Corn harvesting emasculation machinery and peeling machinery are in short supply. The sowing precision quality of the developed plot sowing equipment is not high, the mechanical damage of the plot harvesting equipment is large, and the impurity content is high after harvesting. Restricted by the overall level of the domestic manufacturing industry, the durability of mechanical equipment is not high enough.

Conclusion. It is expected that in the next 10 years, the development trend of the global field breeding mechanization technology will be focused on development and application. There is a large demand for mechanization technology and equipment for field breeding on the domestic market, and the field breeding equipment (instrument) has a good market prospect. With the great support and attention of various countries to the breeding industry, field breeding instruments provide breeders with efficient, fast and accurate technical means for breeding parents and expanding population. Field breeding mechanization will inevitably replace artificial breeding production.

There are several suggestions on the future development of experimental equipment:

1. Pay attention to and speed up the research and development of intelligent, information and standardized technology of breeding test machinery and equipment.

2. Establish mechanization breeding experimental demonstration area of agricultural machinery and agronomy integration, and form a complete breeding regional test and other experimental mechanization technology system.

3. Research on crop phenotypic information technology should be carried out to obtain the data of various traits in each critical breeding period.

4. The technology of continuous acquisition and automatic monitoring of plant morphology, soil and mass ecological environment, plant biochemical tissue and physiological characteristics of crop breeding materials were studied by integrating multi-source information acquisition methods such as video images, multispectral and sensors.

5. Based on the monitoring data, the digital model of breeding materials was constructed, and the information fusion and auxiliary analysis of typical crop breeding process were implemented, as well as variety auxiliary screening and variety adaptability evaluation.

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Conflict of interest.
The authors declare no conflict of interest.

Coauthors' contribution:
Shang Sh. – scientific guidance, formulating the main directions of the study, developing the theoretical background, finalizing the text, drawing general conclusions and literary analysis.
Wang J. – preparing the initial version of the article, monitoring the reliability of combine harvesters, processing the study results, visualization.

All authors have read and approved the final manuscript.

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