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Editorial

Agriculture and crop science in China: Innovation and sustainability

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ABSTRACT

The International Crop Science Congress (ICSC) is a regularly held event allowing crop scientists from around the world to integrate current knowledge into a global context and international applications. The 7th ICSC was held August 14–19, 2016 in Beijing, China, with the theme "Crop Science: Innovation and Sustainability". The congress included eight thematic areas: crop germplasm and evolution, crop genetics and genomics, crop biotechnology, breeding and seed production, agronomy and crop physiology, climate change and sustainability, crop quality and processing, and crop production and socioeconomic aspects. As a companion production for this great congress, the nine papers collected in this special issue feature important fields of crop science in China. This editorial first briefly introduces the 7th ICSC, followed by a brief discussion of the current status of, constraints to, and innovations in Chinese agriculture and crop science. Finally, the main scientific points of the papers published in this special issue are surveyed, covering important advances in hybrid rice breeding, minor cereals, food legumes, rapeseed, crop systems, crop management, cotton, genomics-based germplasm research, and QTL mapping. In a section describing future prospects, it is indicated that China faces a full transition from traditional to modern agriculture and crop science.

1. Introduction

Crops provide human with important products, including food, feed, vegetables, cooking oil, fibers, woods, and medicines. As the global population increases, we face great challenges in providing more crop products to feed the world from decreasing arable land with insufficient water and frequent natural disasters. Crop science has gained increasing importance in meeting these challenges in a globally warming environment, and ensuring food security through scientific and technological advances has become the goal of all countries worldwide. Sustainable crop production and global food security depend on innovation in multiple fields of crop science and technology, including genetics, breeding, agronomy, crop physiology, germplasm resources, grain chemistry, grain storage and processing, crop management practices, crop biotechnology, and biomathematics.

As the Olympics of crop science, the International Crop Science Congress (ICSC) is a regular event allowing crop scientists from around the world to integrate current knowledge into a global context and international applications. It provides an excellent opportunity for participants to share the latest global progress in crop science and develop recommendations for future thrusts in research, development, and technology transfer. The congress has been held every four years, beginning in July 1992. The first ICSC was held in Ames, Iowa state, USA in 1992, and subsequent events were in India (1996), Germany (2000), Australia (2004), South Korea (2008), and Brazil (2012). Hosted by the Chinese Academy of Agricultural Sciences (CAAS) and Chinese Society of Crop Science and organized by the Institute of Crop Science, CAAS, the 7th ICSC was held on August 14–19, 2016 in Beijing, China. As indicated by the congress theme, "Crop Science: Innovation and Sustainability", the 7th ICSC featured 19 plenary speeches, over 300 workshop talks, and more than 900 posters and was attended by over 2000 participants from over 70 countries. The scientific topics covered crop germplasm and evolution, crop genetics and genomics, crop biotechnology, breeding and seed production, agronomy and crop physiology, climate change and sustainability, crop quality and processing, and crop production and socioeconomic aspects.

As a large country with many crop scientists, China has a wide range of climatic and ecological environments, diverse plant species and cropping systems, and different regional needs for food supplies and crop products. As a companion production for the 7th ICSC, we invited representative scientists from China to address important issues in crop science research, publishing their contributions as a special issue of *The Crop Journal* (Volume 5, Issue 2, 2017). In this paper, we will first provide a general discussion of agriculture and crop science in China, including current status, constraints, and scientific innovations. We will then summarize the articles published in the special issue.

2. Agriculture development in China: current status and constraints

As a Chinese saying goes, food is heaven to the people. As a large country with a population exceeding 1.36 billion, China considers feeding its people to be the most important priority in its national economic and social development. Agriculture is a foundation industry, and agricultural modernization is essential for enhancing integrative agriculture production capacity, establishing a mechanism for ensuring long-term food security, and promoting environment-friendly and sustainable

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development. To reach the strategic objective of innovation-driven national development, it is fundamentally important to further promote agricultural scientific and technological innovation and to guide modern agricultural development toward efficient production, product safety, resource economy, and environment–friendly improvement.

Chinese agriculture started during the Neolithic period and this farming culture has persisted for thousands of years. Rapid development in agriculture and rural economy has been achieved since the founding of the People's Republic of China. China now produces 25% of the world's food, feeding about 20% of the world's population with <9% of the world's arable land, and has completed the transition from a food-aid recipient country to a food-aid donor.

In the past five years, China has made a series of notable achievements in modern agricultural production. First, integrative production capacity has reached a new plateau, with an annual grain production of over 620 million tons in 2015, marking 12 consecutive annual increases. Second, farmer income has reached a new level, with a rural per capita disposable income of 1739 US dollars in 2015, the sixth year in which this income increased at a higher rate than either gross domestic product or urban per capita disposable income. Third, agricultural production and technical equipment have developed to a new level, with over 56% of the advance having been contributed by science and technology, indicating the transition of Chinese agriculture and crop production from a resource-input-driven enterprise to one driven largely by science and technology. Integrated mechanization of farming, including land preparation, planting and harvesting, has been realized for 63% of production processes, indicating a transition of the way agricultural products are produced from an operation driven largely by human and animal power, lasting for thousands of years, to one driven largely by machines. Over 52% of farm land has been effectively irrigated, and the situation of dependence on chance for rainfall is changing. Fourth, further reforms in crop production and land-use systems, establishment of new agricultural management models, and development of moderate-scale agrobusiness in multiple ways have contributed to the sustained increase in rural development potential.

However, China is still at a critical point of agricultural transformation from traditional to modern methods. Compared with rapid development in industrialization, informatics deployment, and urbanization, progress in agricultural modernization has been relatively slow. It should be noted that crop and food production capacity in China is still not stable and has limited support from science and technology, innovation and informatics remain at a relatively low level, and agricultural equipment needs improvement. Agricultural development in China should focus on the holistic approach of ensuring national food security and building a moderately well-off society in all aspects. Agricultural modernization and structure reform must be sped up. Specifically, strenuous measures should be taken to increase crop and food production capacity continuously to ensure national food security, broaden approaches to improve farmer income, improve both production and management processes to ensure the quality and safety of agricultural products, strengthen environmental protection with efficient use of agricultural resources to provide support for sustainable agricultural development, promote agricultural system transformation and structure adjustment to accelerate agricultural modernization, and balance urban and rural development by transferring the surplus rural labor force to cities.

3. Scientific innovation in agriculture development in China

Since the founding of the People's Republic of China, scientific and technological innovation has received great attention, and innovation capacity in agriculture, particularly in crop science and technology, has been greatly improved. To be more specific, major crops are now largely represented by cultivars with improved quality and yield potential, and livestock and poultry breeds have been increasingly replaced by improved breeds. As a result, improved high-quality cultivars and breeds have contributed over 43% of the production increase in agriculture. Application of new technologies and scientific products has resulted in a reduction of nitrogen and phosphorus emissions by over 60% and of soil and water loss from sloping cropland by over 50%. It has also contributed a greater than 20% increase in overall farmland productivity.

Progress in agricultural science and technology can be summarized under three headings. First, agricultural innovation capacity has been substantially enhanced. The establishment of research platforms for functional genomics, proteomics, metabonomics, and other molecular techniques has facilitated deciphering the molecular bases of important agronomic traits such as yield, quality, and biotic and abiotic stress tolerance, contributing to the development of theories and methods for crop improvement. Advances in building mathematical or computational models for crop growth and development, organ morphogenesis, assimilate partitioning, and yield formation have improved agricultural simulation and computational technology. Progress in finding new materials, designing new potential targets, and elucidating the functional mechanisms of medicinal components has greatly boosted the discovery of livestock medicines.

Second, key industry technologies have experienced repeated breakthroughs. Construction of platforms for chip-assisted genomic selection, cell engineering, and breeding informatics has stimulated the development of a modern seed industry. Breakthroughs in developing monitoring and warning systems for integrated management of major diseases and insect pests in agriculture have helped to establish new and environment-friendly approaches for prevention and control of epidemic diseases in major crops and livestock. Development of a series of slow-release fertilizers has made China the largest country for their production and consumption. Large combine harvesters and intelligent technologies such as those supported by the Beidou satellite navigation system have revolutionized the agricultural machinery industry. Breakthroughs in processing techniques such as high-throughput, automatic extraction and separation of agricultural products, and environment-friendly and low-energy drying technology have driven advances in the food processing industry. Key technologies in agricultural internets, including wireless sensor networking, cloud communications, intelligent information processing, and cloud computing, have resulted in end-to-end tracking systems for major agricultural products.

Third, technical innovation has greatly improved the utilization of agricultural resources. Establishment of theories and methods for water saving and deployment of high-yield and improved-quality crops has contributed to the development of an integrated technological system for agriculture in arid and semiarid regions. Straw briquets, biomass pyrolysis oil, and biogas have been used as fuels on a large scale. Rice straw mulching technology adopted in the southern hill regions, including Yunnan and Guizhou provinces, has reduced water and soil loss on sloping land by 70% and increased soil productivity by 20%.

Although encouraged by the progress made by science and technology, we need to recognize the challenges in front of us. As it becomes increasingly difficult to ensure food security and a reliable supply of agricultural products, we need to achieve breakthroughs in a series of agricultural technologies, including breeding, sustainable and efficient crop production, healthy livestock and poultry rearing, agricultural mechanization and standardization, and preparedness for and mitigation of agricultural disasters. To promote agricultural production, we need to accelerate development of modern breeding technology, achieve breakthroughs in agroinformatics technology required for precision agriculture, and strengthen research in and development of technologies for full mechanization and standardization in agriculture. Because of the increasing challenges posed by resource shortage and consumption, we need to strengthen key technical innovations in efficient use of agricultural resources, water-saving agriculture, medium- and low-yield cropland improvement, and farmland ecological environment protection and restoration. To catch up with the rapid development in agricultural industries, we need to accelerate research and development in key technologies for seed production, medicine, vaccines, fertilizer, feeds, and next-generation agricultural facilities and informatics equipment.

As the leading agricultural research institution at the national level, CAAS has played an important role in agricultural development and crop science in China, including original innovation in science and technology, breakthroughs in key technologies, and industry support and development. To achieve the development goals of a world-class agricultural research institution, CAAS needs to adhere to its development strategy, reaching for the heavens while keeping its feet on the ground. In this context, we need to make innovative contributions to meet major national demands while seeking international academic excellence in the frontiers of agricultural science and technology. We need to make breakthroughs in the current challenges of agricultural development while facilitating "meristem differentiation" in key areas for the future. We need to solve the global, strategic and key scientific and technological issues in rural economic development while playing a leading role in regional agriculture to solve regional bottleneck issues and support changes in regional agricultural production modes. We need to lead agricultural science and technology innovation and discovery while promoting the transformation and commercialization of scientific and technological achievements. Since the Twelfth Five-Year Plan (2011–2015), science and technology innovation in CAAS has been accelerated by many major scientific research achievements, greatly enhancing industrial support capacity. During the Thirteenth Five-Year Plan (2016–2020), CAAS will continue to play a key role as a reform pioneer, national innovation team, and decision advisory board by constructing a modern academy, strengthening collaboration with international partners, and building up a world-class agricultural research institution. CAAS aims to lead agricultural innovation in both China and the world.

4. Crop science: innovation and sustainability

Crop science is an important component of agricultural science and also the key to ensuring world food security, promoting sustainable utilization of agricultural resources, and effectively protecting agricultural environments. As an addition to presentations and talks delivered at the 7th ICSC, nine papers are included in this special issue addressing innovation and sustainability in crop science. These articles describe advances in crop science and technology in the following representative fields: hybrid rice breeding, production and genetic improvement of minor cereals, food legume production, rapeseed research and production, cotton evolution and domestication, cropping system innovation, rice agronomic management, genomics-based germplasm research, and QTL mapping. In this section, we will highlight the main scientific points of the papers.

4.1. Hybrid rice breeding

As one of the major Chinese crop science contributions to the world, hybrid rice has been planted on over 50% of the rice land in China. It has experienced innovations from three-line to two-line systems and from *indica* × *indica* to *japonica* × *japonica* and *indica* × *japonica* hybrids [1]. In this special issue, Professor Longping Yuan reports the progress in hybrid rice breeding through four phases of high-yield breeding to achieve yield improvements from 10.5 t ha^{-1} in phase I to 15.0 t ha^{-1} in phase IV [2]. He expects that hybrid rice will continue contributing to world food security.

4.2. Production and genetic improvement of minor cereals

In addition to major cereals such as rice, maize, and wheat, many minor cereals contribute greatly to Chinese agriculture, enriching Chinese food supplies. Planting areas and relative importance of minor cereals, compared with each other and with major cereals, have risen and fallen with government policies and changes in consumer preferences and lifestyles. Given that several minor cereals show strong drought tolerance and high fertilizer use efficiency, they provide new opportunities for developing environment-friendly crops and a more diverse food supply for humans and animals. In this special issue, Diao [3] describes the distribution and ecoregions, origin and domestication, and landmark varieties of six minor cereals in China, including foxtail millet, sorghum, oat, barley, common millet, and Job's tears.

4.3. Food legume production

Legumes are grown primarily for their seeds for food or oil, for livestock forage and silage, and as soil-improving green manure. China has a great variety of legume species because of its vast territory and complex ecosystems. Food legumes in China include those used for dry grains and vegetables, excluding soybean and groundnut, which are treated as oil crops. As an important crop category in Chinese traditional and sustainable agriculture, food legumes provide substantial dietary protein and vitamin B and diverse food dishes, ensuring the basic health of Chinese people. Li et al. [4] review the areas and production, cropping systems, and export and import of six major Chinese legume crops including pea, faba bean, common bean, mung bean, adzuki bean, and cowpea. Regular cropping systems used for food legumes involve rotation, intercropping, and mixed cropping. As the world's leading producer of peas, faba beans, mung beans, and adzuki beans, China faces an increasing demand for food legumes as a healthy food for improved living standards. Because of increased imports and reduced profits, the planting area and total production of food legumes in China has decreased of late. In contrast, vegetable legumes, as healthy foods with attractive market prices and flexibility in cropping systems, have increased sharply. To increase food legume production, the key is to increase yield potential but reduce production cost. The authors highlight six important issues that should be addressed in the future.

4.4. Rapeseed research and production

Vegetable oils are triglyceride-based and extracted from plants. Edible vegetable oils are used in food, both in cooking and as supplements. China grows five major oil crops: rapeseed, soybean, groundnut, sesame, and sunflower. As the largest oilseed crop and also the fourth largest crop in China after maize, rice, and wheat, rapeseed (*Brassica napus* L.) accounts for about 20% of world production. Hu et al. [5] reviews rapeseed research and production in China, including functional genomics and marker-assisted selection, breeding of rapeseed varieties, and production techniques. The whole-genome sequencing of rapeseed and its two parent species, *B. oleracea* and *B. rapa*, has greatly facilitated functional genomics research including identification of genes for important agronomic traits, with molecular markers having been developed and used in breeding programs. New cultivars have been developed by intergeneric hybridization, pyramiding of superior alleles, microspore culture, and directional selection, particularly for high oil content. The authors also review mechanization throughout the process of rapeseed production and modern techniques for rapeseed field management. It can be expected that with advanced breeding and production technologies, oil yield and quality will be greatly improved, and desirable traits, such as early maturation, high yield, strong resistance to biotic and abiotic stresses, and suitability for mechanization, will be introduced.

4.5. Crop system innovation

China has a long history of developing favorable cropping systems in agriculture, including intercropping and crop rotation, leading to a sustainable ecological system. As global warming becomes increasingly important, cropping systems are undergoing innovation through new variety development, cropping region adjustment, and cropping practice optimization. Deng et al. [6] first analyze the climate warming tendency, indicating a faster climatic warming in China than the worldwide average with large uncertainties in precipitation change. Second, the authors provide evidence that climatic warming will influence major staple crop production in China negatively or positively, depending on specific cropping regions, seasons, and crops. Third, successful adaptation to climate warming has been achieved in China, with greatly improved crop yield and resource use efficiency along with greatly increased soil organic carbon content and reduced greenhouse gas emissions. With the increasing challenge to food security in the face of climatic warming, the authors suggest that further efforts should be invested in new agricultural policy development, knowledge and technology innovation, and climate-smart agriculture practice, with more investment in field infrastructure development to increase cropping system resilience.

4.6. Rice crop management

As one of the most important food crops, rice uses about 50% of the water used by agriculture worldwide. In Asia, about 80% of the fresh water used for irrigation is used for rice. Rice fields contribute to greenhouse gases with 15%–20% of global anthropogenic methane emissions [7], plus nitrous oxide as a combined effect of nitrogen fertilization and water management. Changes in water management can be used to address the concerns associated with emission of greenhouse gases in the rice field. Yang et al. [8] report that alternate wetting and drying regimes increase rice yield while reducing water use, grain arsenic levels, and methane emission. The increase in grain yield water use efficiency is due largely to reduced redundant vegetative growth, improved canopy structure and root growth, elevated hormone activity, and enhanced carbon remobilization from vegetative tissues to grain.

4.7. Cotton evolution and domestication

Cotton is the most important fiber and economic crop in China. Its production area has experienced a large transition from the lower and middle reaches of the Yangtze and Yellow Rivers to northwest China, leading to various changes in cotton production, processing and utilization, and thus cotton science and technology. As a model system for cell fate determination, cellulose biosynthesis and polyploidization, cotton is of broad interest in plant science and crop breeding and has received increasing attention in genomic research. Such efforts will facilitate our understanding of evolution and domestication in cotton and thus promote the development of strategies and methods for cotton breeding and production. In this special issue, Lei et al. [9] report asymmetric evolution and domestication in the A and D subgenomes of allotetraploid cotton. More structural rearrangements and correspondingly more transposable elements, more lost and disrupted genes, and faster evolution have been identified in the A subgenome. Asymmetric domestication is revealed by identification of more positively selected genes for fiber yield and quality in the A subgenome but more for stress tolerance in the D subgenome. By highlighting the asymmetric subgenomic evolution and domestication of allotetraploid cotton, the authors provide valuable genomic information for cotton research.

4.8. Genomics-based plant germplasm research

Many basic and applied studies have been driven largely by genomics and related technologies. Plant germplasm as the treasury of agriculture has played a critical role in providing resources for long-term crop improvement, which has been revolutionized by the incorporation of genomic tools and methodologies. Jia et al. [10] coin the term "genoplasmics" to describe genomics-based plant germplasm research (GPGR) through integration of germplasm research with genomics. The authors first describe challenges and opportunities in plant germplasm research, based largely on the concept of a core collection, including the establishment of crop core collections based on genomic information, genomics-based germplasm enhancement, and genomics-based gene discovery through map-based cloning, genomewide association studies (GWAS), allele mining, and comparative genomics. As the authors predict, genoplasmics is opening a new era in germplasm research.

4.9. QTL mapping

Crop improvement has been driven largely by genetics and its associated breeding methodologies. As most agronomically important traits are quantitatively inherited, genetic manipulation of quantitative trait loci (QTL) has received great attention, including the development of statistical methods and tools for QTL mapping. Several research groups in China have contributed to QTL mapping, including dynamic QTL mapping strategies [11–13], genetic mapping of QTL × environment interactions [14], and a modified algorithm for composite interval mapping [15]. Recent developments in sequencing, high-throughput genotyping, and GWAS have revolutionized genetic mapping. Chinese scientists have embraced these developments by using new mapping strategies for gene discovery and crop improvement. Xu et al. [16] summarize advances in and limitations of family- and natural population-based mapping, describe statistical methods for improvement of detection power and computational speed, and outline emerging fields including large-scale meta-analysis. New technologies such as next-generation sequencing have created challenges and urgent needs for powerful population design, advanced statistical strategies, and precision phenotyping.

5. Future prospects

China is now facing great challenges in a full transition from traditional to modern agriculture and crop science. Three major innovations must be realized: a transition of agricultural production from partial to full mechanization, a transition of resource utilization from low to high efficiency, and a transition of crop management from high to low input. Such transitions can be achieved only with the development of new cultivars and crop management systems for fully mechanized, resource use-efficient, and management-efficient crop production. The basic requirements for these innovations include increased farm size, reduced production cost, and integrated product pipelines. Diverse crop products with high and stable yield and improved quality will be required to meet the future challenges in agriculture. Integrative use of modern agriculture and crop science and technologies will secure our food supply.

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Cover: Harvesting maize by a combine harvester. Chinese agriculture faces a transition of agricultural production from partial to full mechanization. In maize, harvesting cobs by hand or machines has to be replaced by harvesting grains. A special national yield test program has been established in China to identify newly developed varieties for their suitability for harvesting grains. The photo was taken on October 8, 2016, in Linwei, Weinan, Shaanxi, one of the nation testing sites, by Yunbi Xu, the technical editor of The *Crop Journal*.

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