Current Status and Challenges of Rice Production in China

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Abstract: Rice production in China has more than tripled in the past five decades mainly due to increased grain yield rather than increased planting area. This increase has come from the development of high-yielding varieties and improved crop management practices such as nitrogen fertilization and irrigation. However, yield stagnation of rice has been observed in the past ten years in China. As its population rises, China will need to produce about 20% more rice by 2030 in order to meet its domestic needs if rice consumption per capita stays at the current level. This is not an easy task because several trends and problems in the Chinese rice production system constrain the sustainable increase in total rice production. Key trends include a decline in arable land, increasing water scarcity, global climate change, labor shortages, and increasing consumer demand for high-quality rice (which often comes from low-yielding varieties). The major problems confronting rice production in China are narrow genetic background, overuse of fertilizers and pesticides, breakdown of irrigation infrastructure, oversimplified crop management, and a weak extension system. Despite these challenges, good research strategies can drive increased rice production in China. These include the development of new rice varieties with high yield potential, improvement of resistances to major diseases and insects, and to major abiotic stresses such as drought and heat, and the establishment of integrated crop management. We believe that a sustainable increase in rice production is achievable in China with the development of new technology through rice research.

Key words: Biotic and abiotic stresses, Crop improvement, Crop management, Grain yield, Rice research, Stress tolerance.

Rice is the staple food for more than 65% of the Chinese people (Zhang et al., 2005) and is the subsistence crop for most resource-poor rice farmers and consumers in rural areas of China. The annual total planting area for rice was 29.4 million hectares in China in 2006, which is 19% of the world’s planting area, and is the second largest after India (FAOSTAT, 2007). China ranks first in total annual rice production (about 184 million tons in 2006) and produced 29% of the world’s rice in 2006 (Fig. 1A, B). Among all food grain crops in China, rice occupies 35% of the planting area but accounts for 41% of total grain production according to data of 2006 (FAOSTAT, 2007). Rice is grown in almost every province in China except for Qinghai. Three-quarters of the rice area is planted with indica rice varieties and the rest with japonica rice varieties. Indica rice varieties are generally grown in the south and japonicas in the north. Hybrid rice varieties occupy about 50% of China’s rice-planting areas (Yuan, 2003). Two to three rice crops can be grown in the southern provinces within a year but only single-season rice is grown in the north. More than 95% of the rice is produced under flood-irrigated conditions (Maclean et al., 2002).

Rice production in China has more than tripled in the past five decades mainly due to increased grain yield rather than increased planting area (Fig. 1). The increase in grain yield has resulted from the development of new varieties such as semidwarf varieties in the 1950s and hybrid rice varieties in the 1970s and from improved crop management practices such as nitrogen fertilization and irrigation. Rice yield potential increased by about 30% due to the development of semidwarf varieties (Fang et al., 2004) and additional 15–20% increase was achieved by the use of heterosis (Yuan, 2003). National average rice yield was 6.27 tons per hectare compared with the world average of 4.11 tons per hectare in 2006 (Fig. 1C). However, yield stagnation of rice has been observed in the past ten years in China. Total rice production in 2006 was 9% lower than in 1997, when the country had its biggest rice harvest in history (FAOSTAT, 2007). According to the projected population increase, China needs to produce about 20% more rice by 2030 in order to meet its domestic needs if rice consumption per capita is to be maintained at the current level (Cai and Chen, 2000). This is not an easy task because of changes in socioeconomic and physical environments related to rice production. Several key problems in the Chinese
rice production system also prevent a sustainable increase in total rice production. The development of new technology through rice research will continue to help overcome these problems.

Government policy plays a vital role in rice production. Domestic market liberalization and rice self-sufficient policy through productivity investment (e.g., R&D, irrigation expansion and other infrastructure) have been and will continue to be China’s major national policies in rice sector (Huang and Rozelle, 2005; 2006). Rice marketing price and off-farm employment are two key driving forces of farmers’ rice production. Off-farm employment (mainly long-distance migration works in urban) has a strong negative effect on both rice cropping intensity by changing double rice cropping to a single rice cropping system and rice planting area within a cropping season. This negative effect can be minimized by increasing rice marketing price. In 2005, Chinese government established a minimum protected price for purchasing paddy rice from farmers. This minimum price has increased over years. In March 2008, the government increased the price of paddy rice by another 10% in order to stabilize the total rice planting areas.

1. Key trends working against an increase in rice production in China

1.1 Decline in arable land

During the last 20 years, arable land in China has declined by 0.25 million hectares every year (Zhài, 2000). More importantly, more of the reduction in arable land has occurred in areas with fertile soils (Tong et al., 2003). This reduction in arable land was largely caused by the construction of new buildings and roads and by reforestation on marginal arable land. Rice is often in a disadvantageous position when it competes with cash crops for planting area. Therefore, most of the future increase in rice production must come from greater yields on existing crop land to avoid environmental degradation, the destruction of natural ecosystems, and loss of biodiversity (Cassman, 1999).

1.2 Looming water crisis

China is known for its scarcity in water resources, with less than one-quarter of the world average per capita (Li, 2006), and rice production alone consumes about 50% of the freshwater resources in China (Cai and Chen, 2000). At the field level, flood-irrigated rice requires two to three times more water than other cereal crops such as wheat and maize (Bouman et al., 2007). The scarcity of freshwater resources now threatens rice production in China, mainly because of the increasing competition for freshwater resources from the urban and industrial sectors. Drought stress is considered the most important constraint in rice production in many rice-growing areas of China (Zhang, 2007). Drought stress can be caused by variation in rainfall across years, uneven distribution of rainfall within a growing season, and inadequate rainfall in many areas. The quality of freshwater resources has also deteriorated because of pollution. Irrigated rice farmers will be forced to diversify their cropping system by growing rainfed rice, aerobic rice, maize, and other dryland crops (Bouman et al., 2007).

1.3 Global climate change

The frequency of natural disasters such as drought and flooding has increased partially because of global climate change (Tao et al., 2003). Global warming reduces rice yield by increasing grain sterility and decreasing biomass production (Yoshida, 1981). A large proportion of grain remains empty when the air temperature is higher than 35°C (Matsui et al., 2000). Severe heat damage to the middle-season rice crop occurred in the southern rice production provinces.
of the Yangtze River basin (Huang et al., 2004; Li et al., 2004). It was estimated that 0.5 million hectares of middle-season rice were damaged by heat stress in Hubei Province in 2003. Out of the affected area, about 0.2 and 0.07 million hectares of rice had a grain-filling percentage of 50% and 30%, respectively (Xia and Qi, 2004). The increase in night-time temperature is greater than that in day-time temperature as a result of global warming (Easterling et al., 1997). Rice grain yield decreases by 10% when night temperature increases during the growing season by 1°C (Peng et al., 2004).

(4) Labor shortage
The expansion of cities has led to a labor shortage for agricultural production in rural areas (Cai and Chen, 2000). In 2001, 15 million laborers migrated to cities in China. Most of these laborers are 18 to 40 years old. Both the quantity and quality of labor for rice production declined markedly (Fang et al., 2004). Consequently, the daily wage of labor for rice farming has doubled in less than ten years.

(5) Demand for high-quality rice
As living standards improve, the demand for high-quality rice increases in China (Zhang et al., 2005). In 2000, 40% of the rice area was planted with rice varieties with high grain quality (Liao et al., 2002). About 400 rice varieties with high grain quality were released in China from 1992 to 2002 (Liao et al., 2002). Rice varieties with high grain quality generally do not yield very high, although no genetic linkage between yield and quality has been found. When rice quality becomes the focus, yield improvement will receive less attention.

2. Key problems confronting rice production systems in China

(1) Narrow genetic background
More than 95% of rice germplasm collections worldwide have never been used in any breeding program primarily because of the technical limitations of the conventional breeding approach (Li, 2005). The direct consequence of this underuse of germplasm resources by conventional breeding approaches is the well-documented low genetic diversity in commercially grown rice cultivars and their vulnerability to biotic and abiotic stresses. The situation is even worse in China because 50% of the rice-planting area is occupied by hybrid rice (Yuan, 2003). Hybrid rice varieties were developed using a few male sterile lines as the female parent (Fang et al., 2004). Most restorer lines used as a male parent are related to tropical indica rice varieties such as IR24 and its derivatives.

(2) Overfertilization
China is currently the world’s largest consumer of nitrogen (N) fertilizers. In 2002, annual N fertilizer consumption in China was 25.4 million metric tons or 30% of the global N consumption (FAOSTAT, 2007). About a quarter of this N was used for rice production in China; therefore, rice in China accounts for about 7% of global N consumption (FAOSTAT, 2007). The average rate of N application for rice production in China was 180 kg per hectare, about 75% higher than the world average (Peng et al., 2002). In Jiangsu Province, the average N rate reached 300 kg per hectare in some counties. Because of the high rate of N application, only 20–30% of N is taken up by the rice plant and a large proportion of N is lost to the environment (Peng et al., 2006). Rice yield increases by only 5 to 10 kg for every kg of N fertilizer input in China, which is very low, if not the lowest among the major rice-growing countries (Peng et al., 2006). Overapplication of N fertilizer may actually decrease grain yield by increasing susceptibility to lodging and damage from pests and diseases.

(3) Overuse of pesticides
It is clear that pesticides are being misused in rice production in China (Fang et al., 2004). In some cases, farmers spray their rice crop weekly to control pests and diseases. On average, rice farmers in China are overusing pesticides by more than 40% (Huang et al., 2003). Farmers were found to grossly overestimate crop losses caused by pests. The average farmer perceived yield losses to be nearly twice the losses that actually occurred when no pest control was used (Escalada and Heong, 2004). Econometric analysis also showed that education and quality of the extension system are the major determinants of how farmers perceive yield loss. Overapplication of N fertilizer is partially responsible for the overuse of pesticides (Peng et al., 2002). In many cases, pest outbreaks were the result of overuse of pesticides because of their effect on the biodiversity of rice ecosystems.

(4) Breakdown of irrigation infrastructure
China’s irrigation infrastructure was established mainly in the 1970s by the central government. Since then, maintenance efforts with existing irrigation systems and building of new irrigation facilities have been very limited (Liu, 2005). Deteriorated irrigation infrastructure coupled with declining freshwater resources will have a strong impact on the total area planted to flood-irrigated rice in China (Huang et al., 2006).

(5) Oversimplified crop management
Because of labor migration and increases in labor wages, the labor input for rice production has decreased significantly in China, especially in areas where economic development is more advanced. As a consequence, many rice farmers have greatly simplified crop management practices (Cai and Chen, 2000). For example, some rice farmers apply fertilizers only once before crop establishment for the entire growing season to avoid in-season fertilizer application. Some farmers transplant rice at extremely wide spacing to reduce labor cost. As a result, rice grain yield will...
decline under these oversimplified crop management practices.

(6) Weak extension system
China has about 150,000 agro-tech extension and service stations with 1.03 million staff members (Fang et al., 2004). Because of insufficient financial support from the government, many extension staff members have to earn part of their salary from selling agrochemicals and seeds to farmers. This phenomenon is associated with the overuse of fertilizers and pesticides by Chinese rice farmers (Fang et al., 2004). Furthermore, new technology may not reach farmers because of a weak extension system.

3. Research strategies for increasing rice production in China

(1) Increasing yield potential
Rice varieties with higher yield potential must be developed to enhance average farm yield in order to increase total rice production (Peng et al., 1999). In the past, most progress in the improvement of rice yield potential was achieved when water and nutrients were amply supplied (Peng and Bouman, 2007). China has been at the forefront in developing high-yielding varieties using semidwarf, hybrid, and new plant type breeding approaches. China’s “super” rice breeding project has developed many F2 hybrid varieties such as Liangyoupeijiu and Xiyou9308 using the combination of ideotype approach and intersubspecific heterosis (Yu and Lei, 2001; Min et al., 2002). These hybrid varieties produced grain yield of 12 tons per hectare in on-farm demonstration fields, 8–15% higher than that of the hybrid check varieties. In 1998–2005, 34 commercially released “super” hybrid rice varieties were grown in a total area of 13.5 million ha and produced an additional 6.7 million tonnes of rough rice in China (Cheng et al., 2007). Yield records have been frequently broken by newly developed super hybrid rice varieties. However, the physiological mechanisms underlying high yield potential are poorly understood in super hybrid rice. Crop management strategies for the full expression of yield potential and, at the same time, for achieving high resource-use efficiency have not been developed for these varieties. Many farmers use the same management practices for conventional and “super” hybrid rice varieties (Zou, 2006). Therefore, it is not easy to achieve high yields with the “super” rice varieties consistently across seasons and locations. Because of water scarcity and environmental concerns, the challenge is to increase rice yield with less water and less chemicals (Peng and Bouman, 2007). To achieve this goal, new breeding techniques such as marker-aided selection, transformation, and genetic engineering should be combined effectively with the empirical breeding method. Inputs from physiologists and agronomists are vital for success in this endeavor.

(2) Drought and heat tolerance
Drought and heat have occurred more frequently than ever before, causing high yield losses in the major rice-growing areas of China (Tao et al., 2003). Scientists in China have dissected the genetic basis and mapped the genes (QTLs) in crosses between drought-tolerant germplasm and elite cultivars (Yue et al., 2006). A molecular breeding approach has been used to develop new varieties with drought tolerance. Candidate genes have been identified for engineering drought tolerance in rice (Zhang, 2007). Studies demonstrated significant genotypic variation in high-temperature-induced spikelet sterility and tolerant varieties were identified (Prasad et al., 2006).

(3) Varieties with disease and insect resistance
Rice production in China faces many biotic stresses, which include blast, brown planthopper, bacterial blight, sheath blight, leaf blight, false smut, and stem borers (Wang et al., 2005). Huge yield losses occur due to these biotic stresses every year. Infestations of brown planthopper have become more severe in recent years, probably because of the breakdown in ecosystem stability caused by the heavy use of pesticides and the increase in air temperature associated with global warming. It was estimated that China lost 2.77 million tons of rice because of brown planthopper outbreaks in 2005. Scientists in China have already isolated and cloned many genes with disease and insect resistance from cultivated and wild rice species (Zhang, 2007). These genes with multiple resistances have been transferred into local varieties through transformation or backcrossing. Bt-transgenic rice is a successful example for controlling stem borer although it has not been released officially for commercial production (Huang et al., 2005). For disease resistance, another strategy is to focus on quantitative resistance (mostly polygenic) that provides broad-spectrum resistance against multiple pathogen races or different pathogens (Mew et al., 2004). This can be combined with major resistance genes to achieve a higher degree of and more stable resistance.

(4) Integrated crop management
There is a general consensus among Chinese rice researchers that the contribution of optimal crop management to yield increase is greater than that of planting new varieties (Fang et al., 2004). Various technologies for crop management have been developed in China in the past. Scientists in Jiangsu province developed plant and canopy morphological parameters to guide the crop management at different growth stages for achieving maximum grain yield (Ling et al., 1993; Su et al., 2002). Dry bed instead of wet bed for raising rice seedlings for transplanting has been adopted nationally since 1990s by modifying the technology originated from Japan (Chen, 2003). Another popular practice since 1990s was seedling throwing. In 1999, the total rice planting area using
seedling throwing reached 6 million hectares in China (Zhu, 2000). Rectangular planting with wide spacing between rows and narrow spacing between hills within a row has become a common planting geometry for panicle-weight type rice varieties such as "super" hybrid rice (Zou, 2006). Some of these technologies have contributed significantly to increases in rice yield. However, their impact on the environment and on resource-use efficiency was largely ignored. Socioeconomic assessment was not commonly conducted for each new technology. There was a lack of integration among the different components of crop management practices. New technologies of crop management will have to be developed using systems approaches as rice farming faces many changes in China. The newly developed practices should have a sound scientific basis. Synergy among fertilizer, water, and pest management should be considered to maximize overall efficiency of the production system. New technology will be judged not only based on its effect on yield and farmers’ profit but also based on its short- and long-term impacts on the environment. Sustainability of the rice production system can be maintained only when the natural resource base is protected and ecosystem services of the rice system are maximized. These points have been addressed in our recent study on site-specific nutrient management (SSNM) in six provinces in China and its dissemination through farmer participatory research (Peng et al., 2006; Hu et al., 2007).

4. Conclusions
The Chinese government realizes the importance of sustainable increases in rice production for achieving the nation’s food security. Increases in rice production depend mainly on yield improvement rather than expansion of planting area. The government has invested heavily in rice research. We believe that scientific and technological innovation will continue to play an important role in increasing rice yield despite changes in socioeconomic and physical environments and problems related to rice production. Zhang (2007) recently reported progress toward the development of Green Super Rice by integrating germplasm, genomic resources, and molecular technology in China. These Green Super Rice varieties will have improved resistance to major diseases and insects; high efficiency in nutrient use; resistance to major abiotic stresses such as drought, salinity, and abnormal temperatures; high grain yield; and good grain quality. It is anticipated that the development of Green Super Rice will result in increased rice production with greatly reduced inputs in China.

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