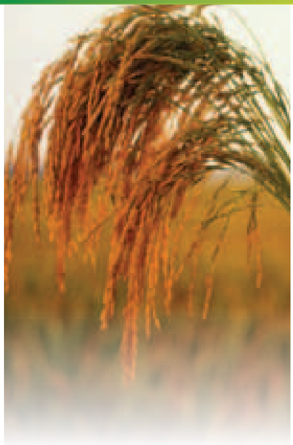

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Pushing the Yield Frontier

Hybrid rice in China

Jiming Li, Yeyun Xin, and Longping Yuan

In the second half of the 20th century, a race was underway in China between a blistering rate of population growth and vigorous efforts to feed an expanding populace by increasing rice production. Efforts in the 1960s to boost rice production gained ground with the introduction of semidwarf rice varieties that increased yields from 2 to 3.5 tons per hectare by 1975. These gains were respectable, but not sufficient. So Chinese scientists started developing even higher-yielding rice.

In 1976, Chinese scientists had made a crucial breakthrough, successfully commercializing what is known as three line hybrid rice, raising yields to more than 5 tons per hectare by 1983. As the technology advanced, nationwide rice yields averaged more than 6 tons per hectare by 1995. And by 2004, yields of super hybrid rice cultivated in selected regions had achieved yields of more than 10 tons per hectare.[1]

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Inspecting a hybrid rice strain

By pushing rice yields steadily and dramatically upward, the development of hybrid rice has allowed China to feed an additional 60 million people a year while reducing the land allocated to rice production by 14 percent since 1978. Hybrid rice now accounts for 63 percent of all land under rice cultivation in China, helping to make it the world's largest rice-consuming country that also is self-sufficient in rice production.[2]

Breakthroughs in Rice Breeding

Historically, food security has been one of China's greatest challenges. Since 1950, China's arable land has been halved from 0.18 to 0.10 hectare per person, while its population has more than doubled from about 560 million to 1.3 billion.[3] Rice imports could not meet China's burgeoning demand—only a small share of global rice production reaches world trading systems. Agricultural production has thus become one of China's top priorities.

China began its effort to develop hybrid rice in 1964 (see box next page). In hybrids, the offspring plants of two genetically distinct parents offer higher yields or other positive traits superior to those of their parent plants (see Chapter 4). But scientists faced special challenges in developing hybrid rice because rice, unlike maize, is a self-pollinating crop, with small florets that contain both male and female organs. To overcome this

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Scientist examines new hybrid rice seed varieties

difficulty, China's rice breeders developed a system that combined three lines, or types, of rice rather than just two. First, a male sterile plant (called the A line) is bred, or crossed, with a genetically identical plant that is not sterile (called the maintainer line, or B line). The resulting plant is another male sterile plant that can then be crossbred with a genetically distinct plant (called the restorer line, or R line). The offspring is then a plant with fertile hybrid seeds.

Scientists spent years searching for and developing A, B, and R lines that could produce rice plants with strong hybrid vigor. China's Ministry of Science and Technology and Ministry of Agriculture put their weight behind this effort, naming the three-line hybrid rice technology one of 22 key research projects in 1971. From 1972 to 1975, scientists tested thousands of hybrids, comparing them with yields from other rice varieties commonly cultivated by farmers. The hybrids beat the yield results of these other varieties by 20 to 30 percent, signaling that hybrids had the potential to generate a significant jump in the country's rice yields.[4]

Still, the early hybrids faced a number of challenges: they were all based on a narrow genetic base, they were susceptible to disease, they produced only one late crop a year, and they produced relatively few grains when cultivated for seed production. As a consequence, farmer adoption of hybrids stagnated. It was not until the late-1970s and early-1980s that scientists introduced more A lines to diversify the genetic base of hybrid rice and develop hybrids with different crop maturity dates and lower vulnerability to diseases and pests. By planting hybrids that were best suited for the agroecological conditions of their land and

History of Hybrid Rice Technology Development in China

1964	China begins research on three-line hybrid rice breeding
1974	Scientists develop first sets of three lines (A, B, and R lines) for a three-line system of breeding hybrid rice
1976	China starts hybrid rice commercialization
1977	Scientists develop systematic techniques for hybrid rice seed production
1987	Hybrid rice acreage surpasses 10 million hectares; China establishes a national two-line system hybrid rice program
1990	Hybrid rice acreage exceeds 15 million hectares
1995	Scientists develop two-line system of breeding hybrid rice
1996	China launches national program to breed super hybrid rice
2000	China achieves super hybrid rice Phase I objectives (10.5 tons per hectare)
2004	China achieves super hybrid rice Phase II objectives (12.0 tons per hectare)
2006	China starts work on super hybrid rice Phase III objectives (13.5 tons per hectare)

by adopting appropriate cultivation practices, Chinese farmers were rapidly able to reap the yield benefits of this new development in rice.

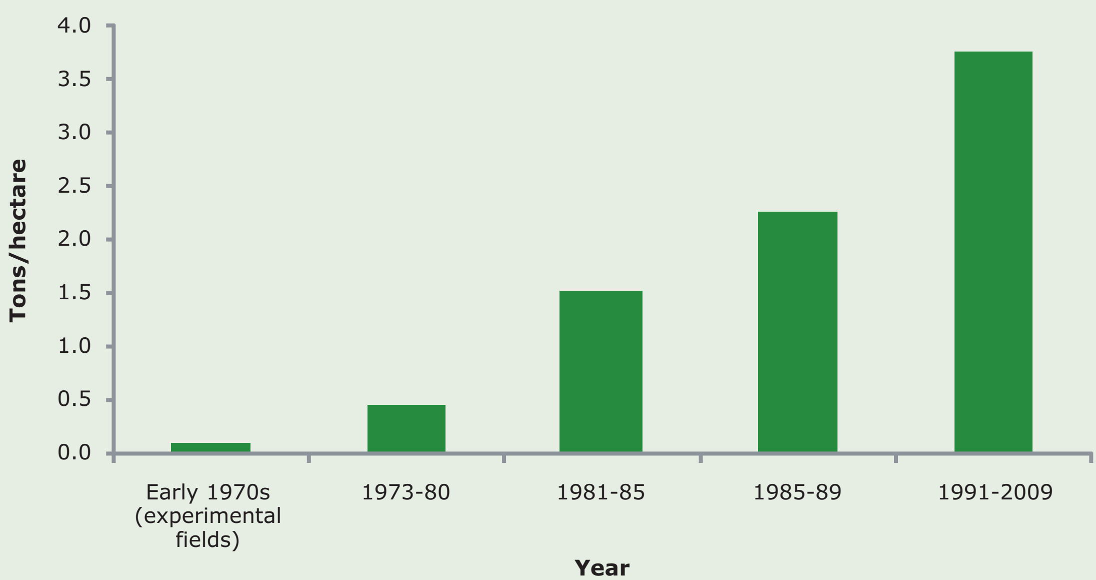
Hybrid rice cultivation also received a boost from concurrent policy reforms that occurred in China during the 1980s—primarily the transition from the collective production system before 1979 to the household responsibility system after 1981 (see Chapter 19), and the liberalization of the rice retail market in 1993. These policy shifts gave rice farmers more freedom to decide what types of rice to cultivate and encouraged hybrid rice breeders to develop hybrids designed to meet consumer preferences rather than strictly meeting production quotas.

Winnowing of harvested hybrid rice

Ramping Up Seed Production

Still, producing enough good-quality, affordable seed to meet the farmers' growing demand for hybrid rice remained a challenge. Without sufficient quantities of seed for farmers, the gains generated through years of research would be lost. Scientists devoted themselves to studying genetics, environmental conditions, and water and fertilizer management in hybrid seed production, and by 1975, they had developed a systematic package of techniques for producing hybrid rice seed. An army of about 30,000 people from rice-growing provinces, including farmers, researchers and technicians, converged on Hainan Island in 1975 to produce hybrid seeds. They succeeded in producing enough seeds to provide the raw material needed to launch large-scale commercial seed production in 1976, which was followed by large-scale hybrid rice cultivation in both southern and northern rice-growing regions (Figure 11.1).

Figure 11.1—Average yields for hybrid rice seed production in China



Source: China National Hybrid Rice Research and Development Center (CNHRRDC). Hunan, China: CNHRRDC.

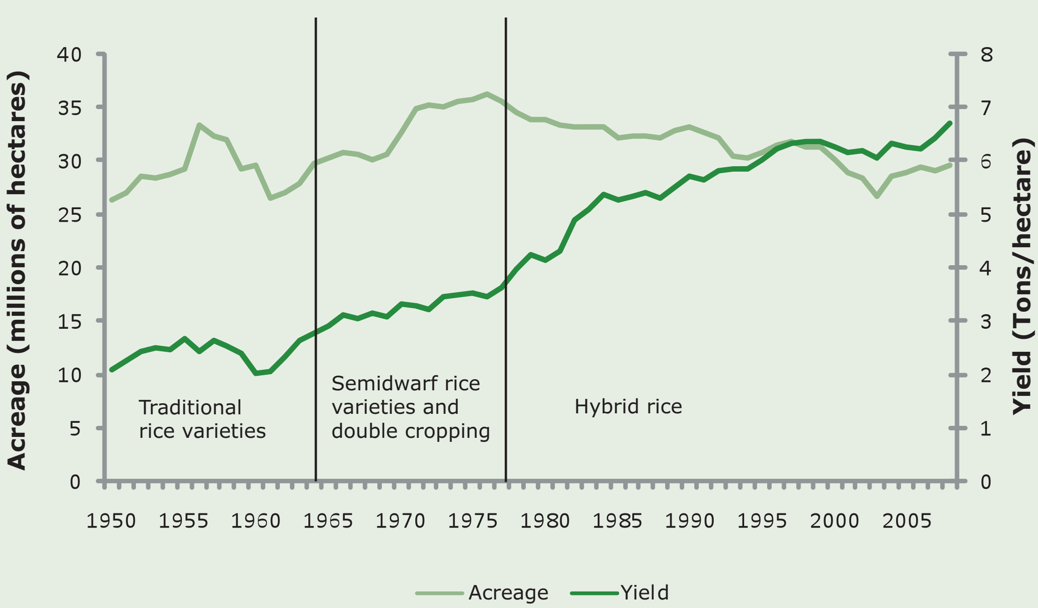
This seed production effort had not only helped to ensure that plenty of high-quality seeds would be available for commercial hybrid rice production, but it also lowered costs for seed businesses and farmers, promoting the fast and steady expansion of hybrid rice production throughout China. Many large hybrid rice seed businesses emerged in the late-1970s with the encouragement and support of the state.

Pushing the Yield Boundaries

In the early-1970s a Chinese scientist discovered a male sterile rice plant whose sterility could be controlled by length of daylight or temperature. In 1987, scientists proposed a way of using this material (called environment-conditioned genic male sterility, or EGMS) to develop hybrids using just two lines. By controlling the male sterility or fertility on the same plant under different environmental conditions, scientists could eliminate a step in the hybrid development process. Besides simplifying the process of developing a hybrid, the new two-line system was more effective in terms of both seed production and commercial rice production. In trials in southern China between 1998 and 2003, a number of two-line hybrids showed remarkable yield increases over the three-line hybrids.[5] Dozens of two-line hybrids were released into commercial production, and by 2008, two-line hybrids occupied 3.3 million hectares of land under rice cultivation, about 11 percent of total rice acreage and 22 percent of total hybrid rice acreage.[6]

But China has worked to push the yield boundaries still further. Encouraged by efforts in Japan and at the International Rice Research Institute to develop super-high-yielding rice, China proposed a super hybrid rice program in 1996. The program set ambitious yield targets: it aimed to achieve 10.5 tons per hectare between 1996 and 2000 (Phase I), 12 tons per hectare between 2001 and 2005 (Phase II), and 13.5 tons per hectare between 2006 and 2015 (Phase III). Indeed, the program achieved its phase-one target in 2000 and its phase-two target in 2004. By 2006, the Ministry of Agriculture had certified 34 rice hybrids as "super rice."[7] Chinese rice breeders are now working on phase three.

Figure 11.2—Rice yields and acreage in China, 1950–2008



Sources: International Rice Research Institute (IRRI). Los Baños, Manila, Philippines: IRRI; Chinese Ministry of Agriculture (MoA). Beijing: MoA.

More Food, Jobs, and Land

Hybrid rice technology has been essential to China's self-sufficiency in rice production. China's total rice production increased from 136.7 million tons in 1978 to 197 million tons in 2008—a 44.1 percent jump—as the hybrid rice program raised the national average yield from 3.4 tons per hectare to 6.7 tons per hectare (a 67.5 percent increase in yield) (Figure 11.2). This growth in production has allowed China to feed an additional 60 million people per year. The concurrent reforms in China's land tenure system also played an important role in promoting hybrid rice cultivation and improving production incentives for farmers.

The fact that hybrid rice's yield advantage has enabled China to cultivate it using less land is also clearly important. China reduced its total rice-growing acreage from about 34.4 million hectares in 1978 to 29.4 million hectares in 2008, a 14.5 percent decrease. Farmers could thus diversify into production of other crops, including high-value crops such as fruits and vegetables, on land not used for rice farming.[8] China's commercialized rice hybrids also have adapted better than conventional inbred rice to a whole range of climatic and geographic conditions, including high-stress environments. Their vigorous root system, strong stem, thick leaves, and high photosynthesis efficiency give them a significant yield advantage in rice-growing regions where environmental stresses are more acute.

Hybrid rice technology has had an impact on China's labor market as well. Hybrid rice research, extension, seed production, and allied industries employ tens of thousands of people, while the hybrid rice cultivation itself has helped to release rural labor into other off-farm areas of employment, such as rural industries.

Keys to Success

One of the most important elements in the successful development and dissemination of hybrid rice was the full support and commitment of the Chinese government. From the research programs of the mid-1960s to today, the government has provided generous funding, conducive policies, and information campaigns that promoted the research, development, and deployment of hybrid rice.

Coordination and collaboration were also critical for developing the new rice technologies. Commercializing both the three-line and two-line hybrid rice varieties took years of cooperative research by hundreds of rice scientists from research institutes and universities. A sophisticated three-tier seed system and four-level research extension network also were key contributors to the success. The three-tier seed system included provincial seed companies to purify parental lines, prefectural seed companies to multiply A lines, and county-level seed companies to produce hybrid seeds. This system ensured a high quantity and quality of the hybrid rice seed for commercial production. The four-level extension network consisted of county, commune, brigade, and production teams to evaluate, select, and promote hybrid rice and appropriate cultivation practices.

Consuming rice, China

Finally, hybrid rice would not have been successful in China without the emergence of a hybrid rice seed industry. Cultivation of hybrid rice increased from 140,000 hectares in 1976 to 18.6 million hectares in 2008, with a commensurate increase in demand for hybrid seed.[9] With a combination of policy support and financial subsidies from the state in the initial phases, the seed industry has gone from a small venture in seed production to a vibrant business sector that now manages large and competitive production and distribution systems.

Lessons from China's Experiences

China's experiences offer a number of lessons. From an institutional and policy standpoint, full government support and commitment were imperative. Government policies and standards made hybrid rice attractive, profitable, and sustainable, and government support was important—especially in the early stages—for research; seed production; and farmers' purchases of hybrid seed, pesticides, and fertilizers.

Furthermore, a national, high-ranking scientist coordinated and oversaw the progress of technology development. Adequate human resources—from full-time researchers all the way to extension workers devoted to publicizing the technology—ensured helpful participation from multiple disciplines related to the technology.

In addition, an effective seed production infrastructure was essential, along with minimum seed quality standards and long-term maintenance of genetic purity of parental lines and hybrid seeds. Given that different ecological rice-growing regions or markets need unique hybrids, it was critical that research and extension infrastructures were regional.

Lastly, comprehensive training programs, which included plot demonstrations, technology workshops, technical briefings, frontline demonstrations, field tours, and mass media campaigns, helped popularize the remarkable yield improvement of hybrid rice.

Conclusion

Even in the wake of the successes of the past several decades, hybrid rice in China faces a number of challenges. Rice farming, which contributes to soil erosion and salinization, has caused considerable environmental stresses. Existing hybrid rice varieties have gradually lost resistance to disease and insects. To maintain and increase yields, Chinese hybrid rice breeders must continually develop new hybrids with multiple resistances to diseases and insects. Yet with a majority of educated young and middle-aged workers moving to metropolitan areas, producing and promoting hybrid rice will become more difficult. Continued investment in agricultural research and continuous innovation in developing, promoting, and sharing new technologies are essential in sustaining the gains achieved by hybrid rice technologies developed in China. ■

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