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EDITORIAL

The Relevance of Rice

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Abstract Research into rice—the world's most important food crop—is crucial for the development of technologies that will increase productivity for farmers who rely on rice for their livelihood. This is particularly the case throughout the developing countries of Asia and is also true for much of Latin America and, increasingly, Africa. The benefits of such increased productivity will flow through to rice-growing countries' landless rural and urban poor, all of whom (1) are net consumers of rice and (2) spend a large proportion of their income on rice. Recent steep rises in the price of rice have amplified the need for investment in high-quality research targeted toward both the intensive irrigated rice-based systems (in which 75% of the world's rice is grown and that must provide the rice for rapidly increasing urban populations) and the rainfed rice-based systems (many of which are characterized by unfavorable environments and extreme poverty).

Keywords Rice · Rice research · Rice prices · Poverty · Food security · Irrigated and rainfed rice production systems · Rice productivity · Climate change

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The price of rice

Rice has always been relevant to global food security and socioeconomic stability. But it was not until one of the steepest price rises in food history that the mainstream media really started to comprehend the grain's importance. As export prices tripled in a mere few months at the beginning of 2008 (Fig. 1), rice became front-page news not only in the Asian countries where it is the staple but also in countries halfway across the world where it is not grown at all and eaten only a little.

The reasons for the rice price increase were numerous, but in many ways, it is research that lies at the heart of the issue. The modern era of farming began in the 1960s when high-yielding rice varieties developed by the International Rice Research Institute (IRRI) in the Philippines were adopted on a large scale throughout Asia. The resultant jump in yields, which heralded the Asian Green Revolution, prompted an era of steadily increasing productivity that kept rice production ahead of the population-growth curve. This, in turn, allowed governments to shore up stocks of rice and prices dropped steadily from the food-crisis peaks of the early 1970s (Fig. 2).

Why is the price of rice, *Oryza sativa*, so important? Domesticated from the wild grass *Oryza rufipogon* 10,000 to 14,000 years ago, this tropical cereal is the main staple for about half of the world's population—more than 3 billion people. It provides about 20% of direct human calorie intake worldwide, making it the most important food crop. Rice consumption exceeds 100 kg per capita annually in many Asian countries (compared with the US average of 10 kg, for example) and is the principal food for most of the world's poorest people, particularly in Asia, which is home to 70% of those who earn less than $1 a day (Fig. 3). For such people, the more productive rice farming

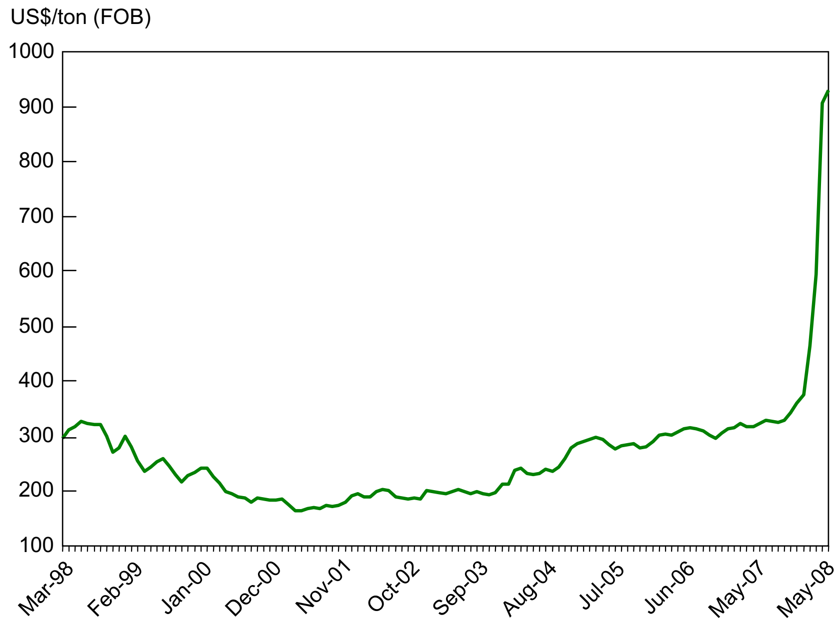


Fig. 1 Monthly export price (US$/ton FOB) of Thai rice 5%-broken, 1998–2008 (March 1998 to May 2008). By the time of publication, rice prices had settled somewhat, but remained around double those of 1 year previously. Source of raw data: The Pinksheet, World Bank.

and lower prices brought about by the Green Revolution had a huge impact on poverty [1].

In Asia, the poorest of the poor spend up to 50% of their total income on rice alone. For them, any money saved on cheaper rice can be used to buy more nutritious food, to meet medical needs, or to clothe and educate children. Furthermore, as rice rapidly gains popularity in Africa, more and more of that continent's poorest stand to benefit from advances in rice research and production.

Therefore, anything that lowers the price of rice will benefit hundreds of millions of poor consumers, and anything that increases rice-farming productivity will benefit millions of rice farmers and their families. The Green Revolution in Asia, spurred by IRRI's development of high-yielding, short-duration, short-stature, fertilizer-responsive rice varieties, did just that and led directly to the Asian economic miracle of the last 40 years [6].

The cheap food myth

As the benefits stemming from agricultural research and development became evident, governments and funding agencies opened their wallets and invested. IRRI's budget,

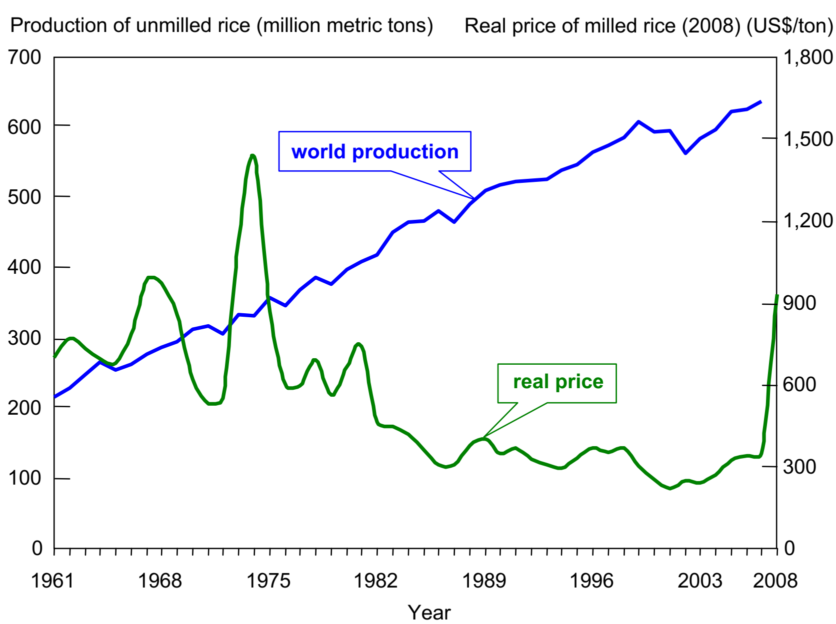


Fig. 2 Trends in world rice production and price, 1961–2008. Source: Production: USDA, 13 May 2008. Rice Price: www.worldbank.org; 2008 is May 2008 price. Relate to Thai rice 5%-broken deflated by G-5 MUV Index deflator (adjusted based on 17 April 2008 data update).

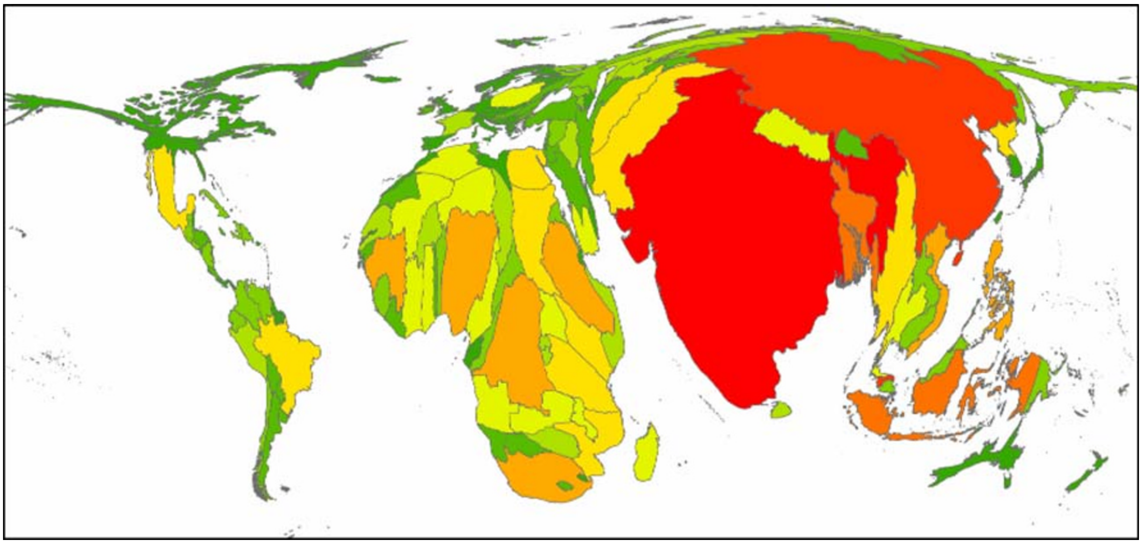


Fig. 3 Cartogram showing country size as a function of the number of people living on less than one dollar per day. Source: R. Hijmans, IRRI.

for example, climbed rapidly from the early 1970s and stayed healthy for almost 20 years. However, in the early 1990s, complacency set in (Fig. 4). Public agricultural research found itself losing out to more fashionable (but worthy) causes such as the environment. The fundamental food problem—producing enough—had been solved. Cheap food was here to stay. Or so people thought.

While funding for institutes like IRRI dwindled, the flow of improved farming technologies slowed. The pipeline did not dry out, but important programs were diminished or cut. The trouble with the idea that the food problem had more or less been solved is that agricultural research is never finished. A new rice variety, for example, may be resistant to a particular disease but not forever. There is no ultimate variety whose development will signal the end of the need for research. We will need agricultural research for as long as we need agriculture.

With the flow of improved technologies stemmed, the productivity growth of the previous decades stagnated (Fig. 5). Sure enough, in the last few years, we have seen clear signs that the world is consuming more rice than it is producing. A steady reduction in stocks is the clearest indicator (Fig. 6).

If there is a positive to be gained from the price spike of early 2008, it is that agriculture—including public agricultural research—is back on the development agenda. Ahead of a United Nations summit held on 3–5 June 2008 to address the current food crisis, Food and Agriculture Organization (FAO) Director General Jacques Diouf talked of "re-launching" agriculture. A key policy document prepared for the Summit calls for support to agricultural research that serves the needs of poor farmers, noting that "high food prices represent an excellent opportunity for increased investments in agriculture by both the public and private sectors to stimulate production and productivity."

Fig. 4 IRRI total funding (inflation adjusted), 1960–2007. Source: IRRI.

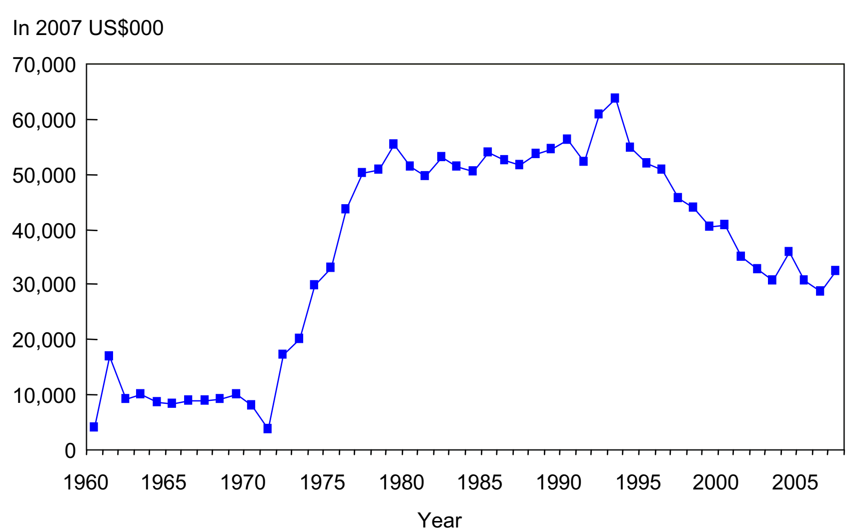
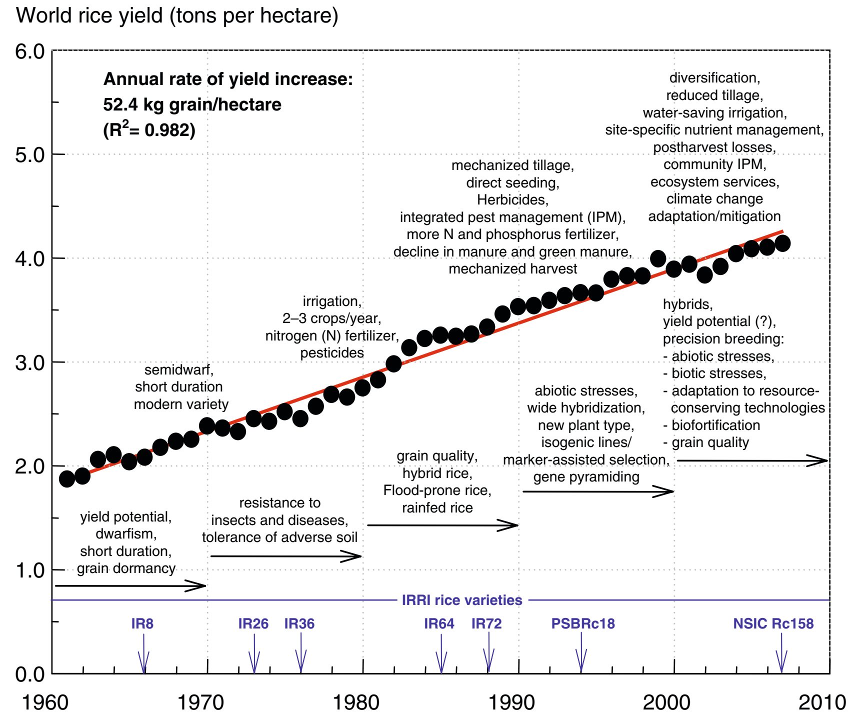


Fig. 5 Trend in average world rice yield (1960 to 2007) and the key technological interventions associated with it. Changes in breeding objectives and release years of selected IRRI rice varieties are indicated in the bottom half. Major changes in management and emerging new management objectives are indicated *above* the yield trend line [4].



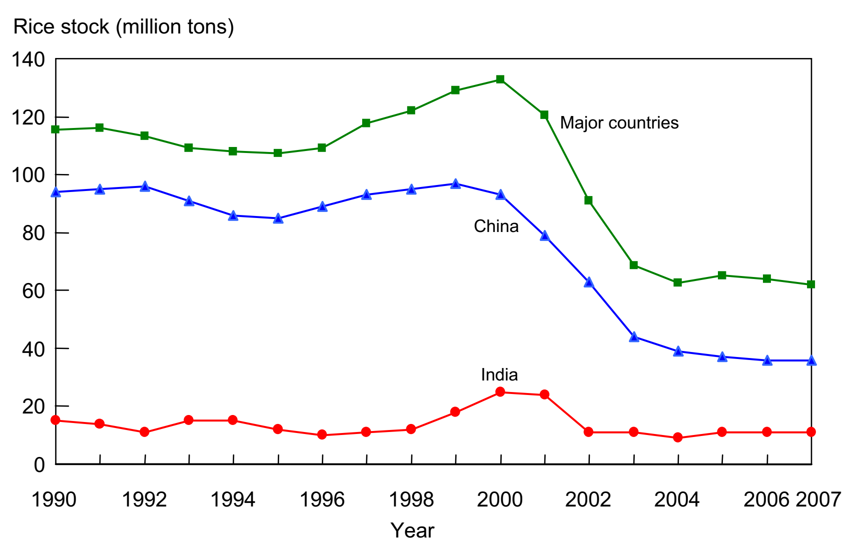
The question, of course, is whether or not the words will turn into the dollars required to revitalize agricultural research and, ultimately, agriculture itself.

Simultaneous research revolutions

Nevertheless, it would be dishonest to paint a picture of utter doom and gloom. Despite the withdrawal of investment in research, the last 15 years have seen some impressive successes. This is true for our understanding of the rice plant and consequent genetic improvements, and it is also true for the less glamorous but equally important agronomic side of the equation: Improvements in crop management incorporating such practices as site-specific nutrient management and conservation agriculture have had demonstrable impact in farmers' fields. Similarly, water-saving practices such as alternate wetting and drying, which allows farmers to grow rice with up to 25% less water, are becoming increasingly important as water becomes an ever scarcer agricultural resource [3].

Simultaneous revolutions in molecular biology and genetics, computational power and storage capacity, and communications have the potential to help scientists

Fig. 6 Rice stocks, 1990–2007. Source of raw data: PSD Online (www.fas.usda.gov/psdonline/psdhome.aspx), USDA, 2008.



dramatically accelerate the pace of their research. Using the information revealed by the sequencing of the rice genome, techniques such as marker-assisted selection allow new varieties to be bred in a fraction of the time required as recently as 20 years ago. Advances in biotechnology are allowing the development of nutritionally enhanced strains of rice that have the potential to avert the hidden hunger of malnutrition that afflicts so many of the poor. The internet, along with exponentially increasing computing power, has permitted scientists the world over to share and analyze vast volumes of data and knowledge. Although it is difficult to know whether this has had significant impact in farmers' fields, it has undoubtedly helped scientists in developed and developing countries improve their research capabilities.

More specifically, several key areas of research are bringing together scientists' increasing knowledge of the biology of the rice plant with work to help farmers improve productivity.

First, researchers are developing, and must further develop, novel and robust approaches to use the wealth of genetic diversity of rice. IRRI is mobilizing the scientific community to establish a public genetic diversity research platform using a variety of germplasm and specialized genetic stocks.

Second, we must continue to develop methods to understand complex traits. By fully exploiting functional genomics tools, it will be possible to bridge the many existing genotype–phenotype gaps [2]. If we take progress in human genetics as a guide—in which scientists have been able to see how complex traits can be defined despite limited capacity to do controlled genetics—much more can be done in rice research in terms of discovering novel genetic control. In many ways, it is not technology that limits researchers, but the resources and investment needed to apply various toolboxes to rice.

Third, we must continue to develop the rice plant as both a crop and biological model for plant-science research and, in so doing, build a critical mass of knowledge directed to solving practical problems. We cannot expect every plant-science graduate to become an agricultural scientist, but having rice as a research model will enable us to tap into a vast pool of talented people and channel their energy and knowledge into solving some of the greatest agricultural challenges we face.

There are two key points in this paper. First, our capacity to perform research—to increase our understanding of the rice plant and the environments in which it is grown and to thus develop technologies that can help millions, if not billions, of people—is greater than ever. Second, given the world's current food situation, the *need* for such research is equally great. The potential is enormous, but it will take commensurate will—political, economic, educational, and scientific—to approach that potential.

Another crucial element, especially for IRRI and its national partners throughout the rice-growing world, is the need to target research toward areas where it is most needed. To do that, we must have the best possible understanding of not only the rice plant, its physiology, and its agronomy, but also the big picture—knowledge of where and how it is grown and by whom, of how it is processed, transported, and marketed, and of how it is consumed and stored.

Rice, global food security, and poverty alleviation

Broadly speaking, rice is grown in more than a hundred countries, with a total harvested area of about 153 million hectares (1 ha=2.5 acres), producing more than 600 million tons annually. About 90% of the rice in the world is grown in South Asia (58 million hectares), Southeast Asia (43 million hectares), and East Asia (31.5 million hectares). In Asia and sub-Saharan Africa (8 million hectares), almost all rice is grown on small farms of 0.5−3 ha. Yields range from less than 1 ton/ha under very poor rainfed conditions to 10 tons/ha in intensive temperate irrigated systems. Small, and in many areas shrinking, farm sizes account for the low incomes of rice farm families.

About 50% of the rice area is grown under intensive irrigated systems, which account for 75% of global rice production. These are systems in which the water supply is assured from either surface sources (rivers and dams) or wells and where controlled drainage is possible. Modern high-yielding varieties do very well under these conditions, and farmers typically apply fertilizer to obtain high and reliable yields. These systems were the home of the Green Revolution in rice, and global food security will continue to depend upon their continued ability to sustain high yields.

The other half of global rice area is rainfed, meaning that it depends exclusively on rainfall and, in some cases, unpredictable floods, for water. Rainfed rice can grow on steeply sloping lands, such as in the mountainous areas of Southeast Asia. But the largest areas are in the flat rainfed lowlands that predominate over much of the delta and coastal areas of South and Southeast Asia. These are level fields in which farmers construct bunds or levees to capture rainwater and maintain standing water in the field for as long as possible. Because rainfall can be so variable, rice in rainfed areas typically is prone to stresses such as drought and catastrophic flooding—sometimes in the same year. Farmers thus rarely apply fertilizer even when they grow improved varieties because these varieties are intolerant of the stresses. For resource-poor farmers, the risk of losing their investment is unacceptably high. Rainfed lowland rice predominates in those areas of greatest poverty (Fig. 7): South Asia, parts of Southeast Asia, and parts of Africa.

Yields are very low (1–2 tons/ha), and farm families remain trapped in poverty. Even though these farmers are very poor, it is important to keep in mind that, for most, without rice, they would have no livelihood at all.

To keep up with the demand and to rebuild rice stocks, the world needs to produce 8–10 million tons more each year than it did the previous year. In 10 years, for example, global production will need to be 80–100 million tons above today's 600 million tons. This is a daunting challenge because, as much of Asia develops economically, urban expansion and industrial development are displacing some of the world's best rice lands. And, in Asia at least, little suitable extra land is available for rice production. Cities and industry also demand water that previously entered irrigation schemes for rice production. Furthermore, in fast-developing countries such as India and China, animal feed is displacing rice as people add protein-rich meat and dairy foods to their diet. At the same time, in many countries where increasing wealth had allowed people to begin to diversify their diets, per-capita rice consumption has started to increase again because higher food prices mean that, once more, people cannot afford the more expensive alternatives. And, unchecked, the burgeoning biofuel industry threatens to displace food crops across the globe.

Therefore, tomorrow's rice needs will have to be met from less favorable lands and using less water. Put in another way, much of the world's extra rice, especially in Asia, will need to come through increased productivity—more per unit area—rather than through establishing new rice fields.

Research challenges ahead

We are rapidly approaching a time when more than half the world's population is urban. It is therefore increasingly important to assure affordable food for the urban poor. Across much of the globe, this means maintaining inexpensive rice supplies, and these must come from the intensive irrigated systems. Boosting the productivity of intensive systems is thus one of the main challenges in rice that must be addressed to prevent global poverty from spiraling out of control. Specifically, in the intensive rice systems, we need research that leads to technologies that can achieve the following:

1. Exploit all options for raising the yield potential of rice. Increasing the yield potential of inbred rice cultivars has proven to be difficult but must be revisited. Hybrid rice improvement may allow for additional yield increases but will require a better understanding of heterosis in rice.
2. Close yield gaps, increase yield stability, and improve net returns through improved germplasm with multiple resistance to abiotic and biotic stresses and improved crop management. Irrigated rice fields can produce

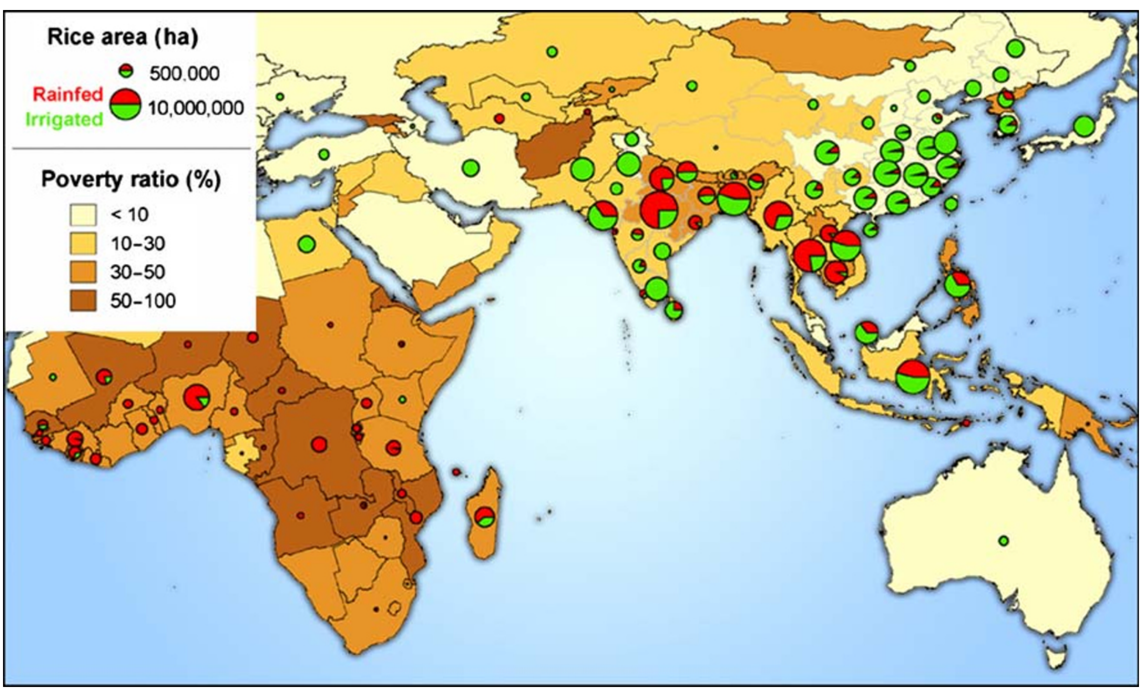


Fig. 7 Poverty and rice distribution and irrigation by country, and subdivisions for China and India. The size of the pie diagram is scaled (not linear) to the total rice area in a country. There is a clear relationship between the prevalence of rainfed rice and the level of poverty. Source: R.Hijmans, IRRI.

stable yields with highly efficient resource use [8], but significant options still exist for developing more stress-resistant varieties through new precision-breeding methods. Likewise, breeding for adaptation to specific rice-based cropping systems and management practices can lead to greater fine-tuning of system performance. Research must also be done on second-generation problems such as partial irrigation due to water shortages, salinity, soilborne diseases, micronutrient depletion, and pest/weed buildup related to emerging crop management and land-use patterns.
3. Add value by improving grain quality and/or the nutritional composition of rice through germplasm improvement and resource management.
4. Develop sustainable management technologies for diversifying rice systems. Researchers must exploit opportunities to increase the productivity of rice in seasons when rice is the best adapted crop (the rainy season) and provide management options for additional crops or the replacement of rice by crops such as maize or vegetables in other seasons. However, diversification may jeopardize the intrinsic sustainability of irrigated lowland rice systems and reduce the amount of rice available for domestic consumption.
5. Manage ecosystem services. We must develop the ability to value, monitor, and optimize a wide range of supporting, provisioning, regulating, and cultural ecosystem services.
6. Understand and adjust to global climate change. Substantial opportunities exist to adapt rice crops and systems to become less vulnerable to climatic extremes, take advantage of rising atmospheric CO_2 levels and, at the same time, emit fewer harmful greenhouse gases and remain profitable for farmers.
7. Improve delivery of technologies. We require a better understanding of the cultural, social, and economic factors that influence the adoption and adaptation of robust integrated technological advances for increased and ecologically sustainable rice production.

A second challenge is to significantly increase the productivity of rainfed lowland rice. Reliable and sustainable productivity increases will increase farm income directly. However, the indirect effects may be greater. Knowing that a crop will give a good yield—even if, for example, it is subjected to full submergence for 2 weeks or a moderately severe drought—will encourage farmers to apply inputs and obtain even higher yields. A reasonable assurance of enough rice to eat and a surplus to sell will provide farmers with the means to invest in diversification and obtain off-farm employment. Most important, perhaps, children will be able to attend school without interruptions caused by crop failures. Such interruptions often result in children being permanently withdrawn from school and condemning yet another generation to poverty [9].

Research has been less successful in producing technologies that will improve the productivity of rainfed systems. However, advances in genomics and molecular biology of rice, enabled by the sequencing of its genome [7]—the first of the crop species—and improved analytical approaches, have allowed rice scientists—breeders, geneticists, and physiologists—to make dramatic progress in developing rice lines that tolerate complete submergence, drought, and salinity. There is now an unprecedented opportunity to make strong contributions to the well-being of farmers and the landless in rainfed systems. The incorporation of major tolerance of complete submergence into varieties already grown on millions of hectares is a concrete proof that this opportunity can be translated into reality [10]. The following work also needs to be done:

1. Identify additional genes conferring tolerance of abiotic stresses. The deployment of cultivars carrying the submergence-tolerance gene shows that such traits can be transferred to widely grown varieties, as its strong effect is independent of genetic background. Genes conferring tolerance of drought and salinity stresses must be identified and evaluated for their expression in different backgrounds.
2. Transfer stress-tolerance genes into present and future mega-varieties (grown on more than 1 million hectares). The most suitable approach is by marker-assisted backcrossing, which can be completed in less than 3 years.
3. Develop new mega-varieties through modern precision-breeding methods. The currently grown mega-varieties are becoming susceptible to new pests, and there is also a need for varieties with higher grain quality that can be sold at a higher price to increase income.
4. Evaluate new breeding lines and improved crop management practices in farmer participatory trials and under different cropping systems. As farmers become more confident in the performance of their varieties under stress conditions, options for diversifying their systems should be explored.

New frontiers: climate change and a new rice engine

Attempting to overcome abiotic stresses for rainfed rice generates a "convenient convergence" in two key ways. First, rainfed rice farmers in Asia and Africa all face the same basic physical constraints to rice productivity. Thus, addressing problems that are important for millions of rice farmers in Asia will also address some of the critical needs of poor rice farmers in Africa. Second, it is increasingly likely that climate change will bring about more severe weather that will translate into droughts, floods, and sea-water intrusion. The development of drought-, heat-, submergence-, and salt-tolerant rice essentially translates into "climate-ready" rice. This will be important for both rainfed systems and intensive irrigated systems.

Taking a longer view, rice research also offers one of the most exciting examples of science in any field: the ambitious plan to reengineer rice photosynthesis to make it similar to that of the more efficient maize, sorghum, and sugar cane. The latter have a photosynthetic mechanism (termed C_4) that reduces losses of fixed carbon and therefore increases biological yield potential by some 30–50%. It also improves water- and nitrogen-use efficiencies. Success here would mean the scientific equivalent of moving from horse-drawn vehicles to the motor car, with "supercharged" rice having the clear distinction of being environmentally beneficial. Since C_4 photosynthesis has evolved independently several times within the grasses and since the metabolic components of the C_4 pathway already exist in rice, the research, still in its early stages, is generating much enthusiasm. It may take as long as 10–15 years of dedicated work by a global scientific team, but C_4 rice could boost yields and increase the efficiency of resource use more than any other advance since the first modern varieties of the Green Revolution.

Conclusions

Agricultural research in a development context does more than simply produce knowledge and technologies that can be used to improve productivity in developing countries. We know that countries that have had access to advances in agricultural technology have done better, economically, than those that have limited or no access. And we also know that regions that the Green Revolution failed to reach, such as sub-Saharan Africa, are now a long way behind those countries that experienced the Revolution not only in terms of existing technologies but also in terms of capability in and access to modern agricultural research techniques. Thus, the gap continues to widen between the countries that missed out and the countries that benefited 40 years ago [5].

Whether or not we realize the potential for science to help solve the previously intractable problems in rainfed systems and also to meet the challenges facing intensive systems depends upon how well acceptable products are developed and how well they can be marketed. The experience and lessons of the rice Green Revolution in Asia and Latin America are that farmers will take up new varieties and enabling technologies on a massive scale, and consumers will eat these varieties as long as the price is attractive and the quality acceptable.

Worryingly, however, when the crisis of the 1970s struck, investment in agricultural research had injected the R&D pipeline with the Green Revolution technologies that were able to help farmers turn things around quickly. The current crisis has hit at a time when investment has dropped off. There *are* technologies in the pipeline, but there could be many more. The new awareness will need to be translated into genuine support if good ideas are to become the technologies we need to keep the world's most important grain plentiful and affordable for all.

It has taken a food crisis that is echoing that of the early 1970s, but after almost two decades, there is a growing realization once again that agricultural research in general and rice research in particular are worthy of major international support. If any rice scientists ever doubted that their career was worthwhile, they need not doubt any longer.

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