Transforming Agriculture

The Green Revolution in Asia

Peter B. R. Hazell

Asia in the mid-1960s was on the brink of disaster. Hunger and malnutrition were widespread after decades of neglected food production compounded by rapid population growth. Back-to-back droughts in India, combined with similar episodes of food insecurity in neighboring countries, drew attention to the region's potentially enormous food deficit. Western powers grew concerned that escalating hunger and poverty would lead to the spread of communism (or red revolution). The effort to increase food production that followed—the Green Revolution—is a crucial chapter in the story of agricultural development in the 20th century.

In response to repeated calls for action, the Rockefeller and Ford Foundations took the lead in creating an international agricultural research program to help adapt new agricultural technologies to conditions in developing countries. Work started with research on rice and wheat, two of the most important food crops for developing countries. The breeding of improved rice and wheat varieties, combined with the expanded use of fertilizers and other chemical inputs, irrigation, and public policies that were supportive of agriculture, led to dramatic yield increases in Asia beginning in the late-1960s.[1] Agricultural yields and output doubled over a period of only 25 years, from 1965 to 1990.

The Green Revolution spread rapidly across Asia, and the resultant increases in food production pulled the region back from the edge of famine. Within 25 years, the region was producing food surpluses. At the same time, the Green Revolution lifted many people out of poverty; made important contributions to economic growth; and saved large areas of forest, wetlands, and other fragile lands from conversion to cropping. This story focuses on the years 1965 to 1985, a defining period for the Green Revolution in Asia, one that dramatically changed the fortunes of billions of people.

A Package Deal

The Green Revolution was, at its most basic level, the introduction of a package consisting of modern inputs—improved seeds, fertilizers, and pesticides—that together dramatically increased crop production. Its implementation also depended, however, on strong public policies and investments in agricultural research and development, rural infrastructure such as irrigation and rural roads, credit provision to farmers, systems to supply the input packages, and price stabilization mechanisms.

Attempts have been made to assess separately the contributions of the different components of the Green Revolution package, but in practice it was the powerful interactions among these individual components that made the difference. Only with all of these components in place did farmers—particularly small farmers—have the right economic incentive to adopt the new packages.

Irrigation, fertilizer, and improved seeds

Asian countries had invested heavily in irrigation before the Green Revolution, and by 1970 around one quarter of the agricultural land was already

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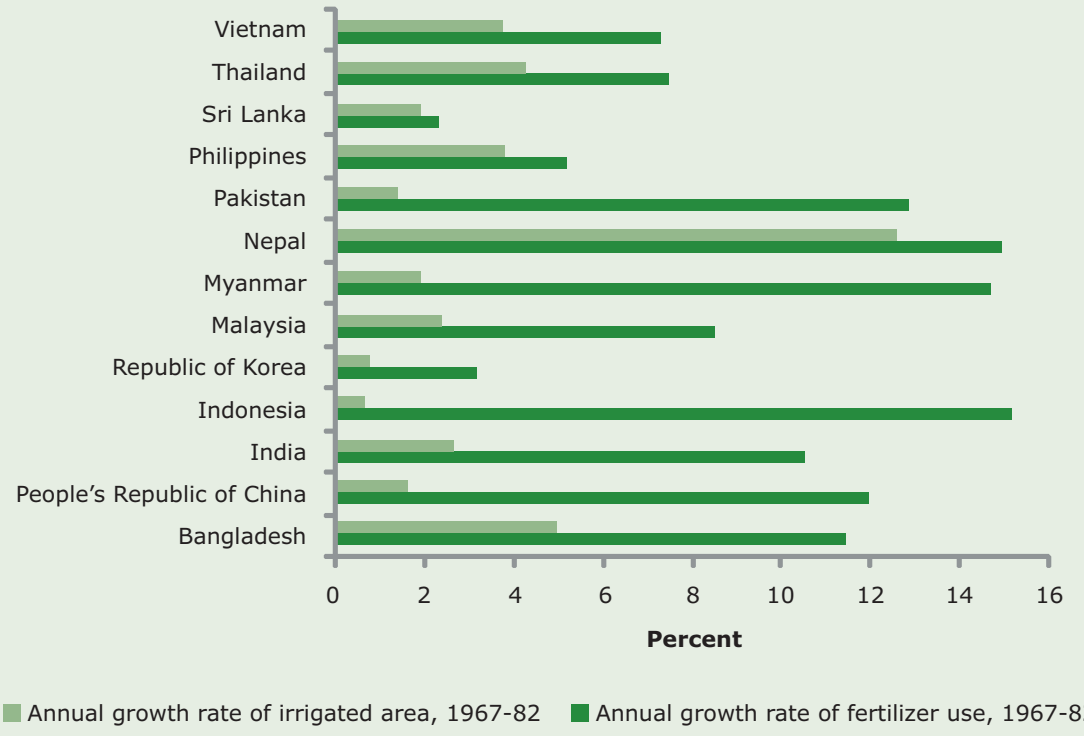
irrigated. India had 10.4 million hectares of canal-irrigated land in 1961 and 4.6 million hectares of tank-irrigated land.[2] But the Green Revolution era brought large additional investments across Asia, and, between 1967 and 1982, irrigated area grew by 2.1 percent a year (see Figure 3.1).

Like irrigation, fertilizer use across Asia was also growing before the Green Revolution. In 1970, Asian farmers applied an average of 23.9 kilograms of plant nutrients per hectare of farmland. The Green Revolution, however, bumped fertilizer use way up. From 1967 to 1982, average use grew by a remarkable 10.75 percent a year (see Figure 3.1).

Irrigation and fertilizer helped raise cereal yields, but their full impact was only realized after the development of high-yielding varieties. Scientists sought to develop cereal varieties that were more responsive to plant nutrients and had shorter and stiffer straw that would not fall over under the weight of heavier heads of grain. They also wanted tropical rice varieties that could mature more quickly and grow at any time of the year, thereby permitting farmers to grow more crops each year on the same land. Varieties also needed to be resistant to major pests and diseases that flourish under intensive farming conditions and to retain desirable cooking and consumption traits.

Borrowing from rice-breeding work undertaken in China, Japan, and Taiwan, the fledgling International Rice Research Institute in the Philippines developed semi-dwarf varieties that met most of these requirements and that could be grown under a wide range of conditions. Similar achievements were made for wheat after Norman Borlaug (later awarded the Nobel Peace Prize for his work) crossed Japanese semi-dwarf varieties with Mexican wheat varieties at what is now known as the International Maize and Wheat Improvement Center in Mexico.

Figure 3.1—Growth of irrigation and fertilizer use during the Green Revolution in Asia



Source: Rosegrant, M. W., and P. B. R. Hazell. 2000. *Transforming the rural Asian economy: The unfinished revolution.* Hong Kong: Oxford University Press.

These high-yielding varieties that powered the Green Revolution were not developed overnight. Rather, they were the product of a long and sustained research effort. Moreover, many of the initial varieties that were released had to be constantly improved and adapted to meet the challenges posed by continually evolving pests, changing environmental conditions, and local consumer preferences.

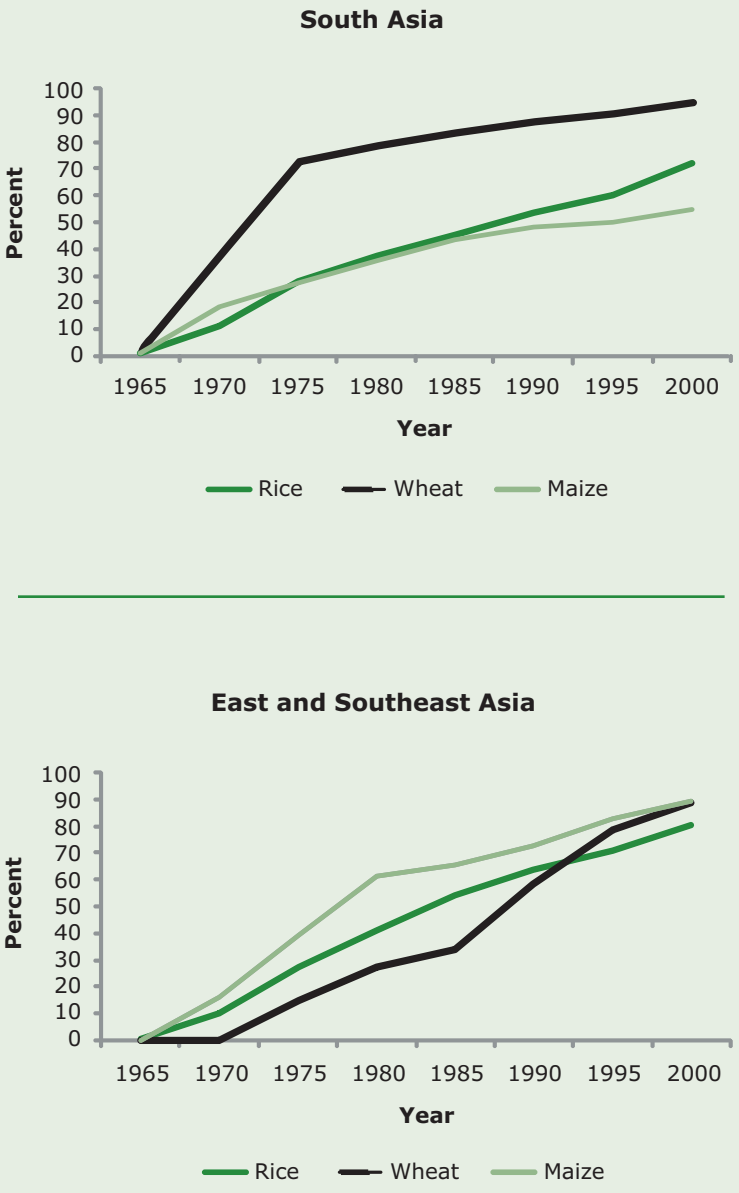
Nor were the high-yielding varieties limited to rice and wheat: high-yielding varieties have since been developed for a number of other major food crops important to developing countries, including sorghum, millet, maize, cassava, and beans.

The adoption of high-yielding varieties occurred quickly (see Figure 3.2), and by 1980 about 40 percent of the total cereal area in Asia was planted with modern varieties.[3] By 2000 this figure had increased to about 80 percent of the cropped area.

Public investment and policy support

The Green Revolution was more than a technology fix. It was also the result of a supportive economic and policy environment. Farmers were educated about the new technology. Systems for delivering inputs and credit were rapidly expanded to allow farmers to adopt and profit from the technologies. Processing, storage, trade, and marketing capacities were ramped up to handle the surge in production. Accomplishing these tasks was considered too large a challenge for the private sector on its own at the time, especially if small farmers were not to get left behind. So, to achieve these ends, governments across Asia actively intervened in launching and implementing the Green Revolution. Some—but not all—public interventions were market-mediated, and all were backed by substantial public investments in agricultural development.

Figure 3.2—Share of harvested area under modern varieties, 1965–2000



Source: Gollin, D., M. Morris, and D. Byerlee. 2005. Technology adoption in intensive post-Green Revolution systems. *American Journal of Agricultural Economics* 87 (5): 1310–16.

The high levels of public investment necessary to launch and sustain the Green Revolution were impressively met. Asian countries not only invested heavily to launch their Green Revolution, but continued to invest in agriculture to sustain the gains that were achieved. On average, Asian countries were spending 15.4 percent of their total government spending on agriculture by 1972 (about 7 percent of agricultural gross domestic product), and they doubled the real value of their agricultural expenditures by 1985.[4] These sustained investment levels were particularly critical for agricultural research and development, where long lead times in developing new products and the continuously changing conditions facing farmers require long-term commitment.

Governments also shored up farm credit systems, subsidized key inputs—especially fertilizer, power, and water—and intervened in markets to stabilize farmgate prices. Many governments used their interventions to ensure that small farms did not get left behind. Substantial evidence at the time showed that small farms were the most efficient producers in Asia, and land reform and small farm development programs were implemented to create and support large numbers of small farms. Small-farm-led agricultural growth proved to be not only more efficient, but also more pro poor, a win–win proposition for growth and poverty reduction. The approach taken in India (see box below) is indicative of what happened in many other Asian countries.

A Boom in Food Production

Average cereal yields grew impressively in Asia: wheat yields grew by 4.1 percent a year between 1967 and 1982 and rice yields by 2.5 percent (see

India's Green Revolution Agenda

Immediately after independence in 1947, the Indian government made agricultural development its top priority. Realizing that India would have to develop the physical and scientific infrastructure necessary to support modern agriculture, Prime Minister Jawaharlal Nehru and his government poured resources into the effort, allocating 31 percent of the country's budget to agriculture and irrigation. Massive irrigation projects, power plants, state agricultural universities, national agricultural research systems, and fertilizer plants sprang up across India. These steps were accompanied by land reform designed to create a more equitable distribution of land.

In the mid-1960s, drought and population growth made India more dependent on U.S. food aid, despite its own agricultural potential. Following a study by the Ford Foundation in the early-1960s, the Indian government set up the Intensive Agricultural District Program to invest heavily in agricultural extension and distribution of subsidized inputs. The government also established the Food Corporation of India, which bought excess production at a guaranteed price in order to provide stability to farmers. The government also took an active role in coordinating interventions from donors and development partners, who financed agricultural extension as well as research and development. All of this came on top of India's considerable existing infrastructure, including roads and irrigation systems—the Indian government coordinated interventions all along the market chain to enable the entire agricultural system to function.

As a result, most rural small-scale farmers could profitably obtain and use inputs such as high-yield seeds, fertilizers, irrigation, and credit. Despite the heavy government involvement in the production, dissemination, and adoption of these inputs, the private sector also had a key role. The dual private and public marketing system actually helped improve the efficient distribution of inputs to farmers. The success of India's Green Revolution arose from the combination of subsidized inputs, public investments in infrastructure (roads, power, and irrigation), research and extension, and, later, marketing policy interventions that assured farmers' access to market outlets at stable prices.

Early breakthroughs in productivity were concentrated in Punjab and Haryana in northwestern India, which became breadbaskets for the entire subcontinent. This agricultural growth cut poverty in the Punjab region significantly, partly because land distribution was relatively equal and the benefits of agricultural productivity improvements reached a large share of the population. In neighboring states like Bihar, where the land system was more feudal, poverty reduction was more limited and growth slowed down sooner.

Table 3.1). Higher yields and profitability also led farmers to increase the area of rice and wheat they grew at the expense of other crops. And with faster-growing varieties and irrigation, farmers grew more crops on their land each year. This change led to even faster growth in cereal production. All these gains were achieved with negligible growth in the total area planted to cereal—just 0.42 percent a year.

On average, total Asian cereal production grew by 3.6 percent a year between 1967 and 1982, with average annual growth rates of 5.4 percent, 3.3 percent, and 4.6 percent for wheat, rice, and maize, respectively (see Table 3.1). The growth rates were considerably higher in the breadbasket areas (such as Punjab and Haryana in India and Central Luzon in the Philippines) where the Green Revolution was launched.

Thanks to this rapid growth, cereal production in Asia virtually doubled between 1970 and 1995, from 313 to 650 million tons per year. Although the population increased by 60 percent, food production rose faster, with the result that cereal and calorie availability per person increased by nearly 30 percent and wheat and rice became cheaper.[5]

Nutrition Improves, Poverty Declines

By increasing the supply of food and reducing prices of food staples in Asia, the Green Revolution benefited poor people's nutrition. Higher yields typically led rural households in adopting regions to consume more calories and protein. One study, for example, found that over a 10-year period the spread of high-yielding rice in the North Arcot district of Tamil Nadu in southern India led farmers and landless workers to consume substantially more energy and protein.[6] About one-third of the calorie increase could be attributed to increased rice production.[7]

Some evidence shows, however, that other nutritionally rich foods like fruits and vegetables have become more expensive as the price of cereals has fallen. A study of Bangladesh showed that a downward trend in the price of rice over the periods of 1973 to 1975 and 1994 to 1996 was accompanied by upward trends in the real prices of other foods that are richer in micronutrients, making these less accessible to the poor.[8] As a result, micronutrient deficiencies are more common today than calorie and protein deficiencies.

Table 3.1—Annual growth rates in cereal production in Asia, 1967–82 (%)

Crop	Area	Yield	Production
Wheat	1.30	4.07	5.43
Maize	1.09	3.48	4.62
Rice	0.70	2.54	3.25
Other grains	-1.76	1.63	-0.15
All cereals	0.42	3.13	3.57

Source: Rosegrant, M. W., and P. B. R. Hazell. 2000. *Transforming the rural Asian economy: The unfinished revolution.* Hong Kong: Oxford University Press.

Although the primary goal of the investments underlying the Green Revolution was to increase food production, evidence suggests that it also helped slash poverty. Reliable poverty data are not available for the early Green Revolution period, but in 1975 nearly three out of every five Asians still lived on less than US$1 a day. This share declined to less than one in three by 1995.[9] The absolute number of poor people declined by 28 percent, from 1,149 million in 1975 to 824 million in 1995. These reductions in poverty would have been even more impressive if the total population had not grown by 60 percent over the same period.[10] The vast majority of the poor who were lifted out of poverty were rural and obtained at least part of their livelihood from agriculture and allied activities.

The relationship between the Green Revolution and poverty alleviation is complex, and there are a number of pathways through which the Green Revolution benefited the poor. By allowing poor farmers to increase their own production, it directly provided them with more food and nutrients and increased the output they could sell to raise farm income. Small farmers and landless laborers gained additional agricultural employment opportunities and higher wages within adopting regions. The Green Revolution also benefited the poor in less direct ways. Soaring agricultural growth in the Green Revolution regions created jobs for migrant workers from other regions. It also indirectly stimulated growth in the nonfarm sector of the economy, both rural and urban, benefiting a wide range of rural and urban poor people. Also, greater food production led to lower food prices for all types of poor people.

A technician teaches farmers about pest-management techniques

Environmental Challenges

Cereal yields have continued to rise on average across Asia since the Green Revolution era, but annual growth rates are slowing. There are several possible reasons for this slowdown: displacement of cereals from better farmlands by more profitable crops like groundnuts; diminishing returns to modern varieties when irrigation and fertilizer use are already at high levels; and the fact that cereal prices have until recently been low relative to input costs, making additional intensification less profitable. But there are concerns that the slowdown also reflects a deteriorating crop-growing environment, and this is supported by growing evidence on the degradation of soils and build up of toxins in intensive paddy systems.

Broader worries have also arisen about the environmental sustainability of the Green Revolution. These wider issues include excessive and inappropriate use of fertilizers and pesticides that pollute waterways and kill beneficial insects and other wildlife; irrigation practices that lead to salt buildup and eventual abandonment of some of the best farming lands; increasing water scarcities in major river basins; and retreating groundwater levels in areas where more water is being pumped for irrigation than can be replenished by the rains.

Environmental concerns have led to new research and a wider array of more sustainable technologies and farming practices. A number of approaches are now being tried to make intensive Green Revolution farming sustainable. More careful and efficient management of soil nutrients, including new ways of applying fertilizer, can increase the efficiency of fertilizer use, thereby reducing production costs and environmental problems. Low- or zero-tillage farming can save labor, fertilizer, and energy, minimize planting delays between crops, conserve soil, reduce irrigation water needs, increase tolerance to drought, and reduce greenhouse gas emissions. Researchers have shown the potential for raising yields in irrigated farming while saving substantially on water use. Integrated pest management combines pest-resistant crop varieties, natural pest control mechanisms, and the judicious use of some pesticides to give farmers significant cost savings on pesticides and improve farmers' health. Still, far too few farmers use these more sustainable technologies and farming practices. Reasons include the high levels of knowledge required for their practice; problematic incentives caused by input subsidies; labor constraints and insecure property rights; difficulties of organizing collective

action; and preverse incentives that arise when most of the environmental damage occurs off-site. These constraints require more calibrated policy responses, and developing these remains a major challenge for the future management of Green Revolution areas.

Lessons of the Asian Green Revolution

The Green Revolution was a continuing process of change rather than a single event, and even today scientists and farmers are constantly making improvements to cereal varieties and management practices to help support and advance high levels of productivity. Several important lessons can be drawn from this dramatic period of history.

First, technological barriers to expanded food production among small and large farmers in developing countries can be alleviated. Second, green revolutions do not just happen, but require considerable and sustained nurturing by the state. Third, green revolutions are not necessarily pro poor or environmentally benign, and achieving favorable outcomes requires appropriate supporting government policies.

Overcoming technological barriers to food production

Asia was able to break out of its food production constraint by bringing the force of the 20th-century scientific revolution in agriculture to its farmers. Governments and their international partners invested heavily in agricultural research and development, irrigation, and fertilizer supplies, and farmers made major changes to their traditional and well-honed farming systems. The switch from low-input/low-output farming to high-input/high-output farming was not without its critics, but it sufficed to provide the needed productivity breakthroughs that had otherwise failed to materialize. The initial Green Revolution technology package worked best for wheat and rice in the best-irrigated areas, but within 10 to 15 years the technologies had evolved to accommodate the challenges of many poorer regions growing a wider range of food crops under less-assured irrigation conditions.

Making green revolutions happen

Market forces alone are insufficient for launching green revolutions. Asia's Green Revolution was not a single intervention or a silver bullet, but a set of initiatives and preconditions that came together to ensure that farms of all sizes could participate in a fully functional market chain. These lessons can usefully be divided into a number of preconditions that existed (or were established) and a series of interventions that were implemented to create an enabling and sustained economic environment.

First, if farmers are to adopt Green Revolution technologies, they need access to a holistic package of affordable inputs (fertilizer, improved seed, pesticides, and irrigation water), seasonal credit to buy them each season, and assured access to markets at stable prices. A green revolution takes off only if all these things come together in an integrated way. Achieving these preconditions requires critical accumulated levels of investment in agricultural research and development, extension, roads, irrigation, power, and other infrastructure, as well as effective public and private institutions that serve agriculture. In Asia, these things were built up over several decades in an integrated way—guided by national agricultural development plans—and were already advanced before the Green Revolution.

Second, an enabling economic environment is needed. Although Asian countries discriminated against agriculture in their macroeconomic, tax, and industrial sector policies, they offset many of these biases by subsidizing inputs and adopting price support policies for farmers. The net result was that farmers found it profitable to adopt Green Revolution technologies. Moreover, although the Asian Green Revolution was initiated and driven by governments, the private sector was given an important role, and this helped reduce marketing inefficiencies and corruption.

Third, Asian countries not only invested heavily to launch the Green Revolution, but continued to invest in agriculture to sustain the gains that were achieved.

Making green revolutions pro poor

Green revolutions need to be led by small farmers to be pro poor, but this does not automatically happen without supportive government policies. In Asia, the conditions under which the Green Revolution proved pro poor included (1) a technology package that could be profitably adopted on farms of all sizes; (2) an equitable distribution of land with secure property rights; (3) modern input and credit systems that served small farms at

Former UN Secretary General U Thant (center) examines new rice strains

prices they could afford; and (4) product markets and price support policies that ensured small farms received stable and fair prices. Meeting these requirements typically required proactive efforts by governments in the form of land reforms, small farm development programs, and input and credit subsidies.

Making green revolutions environmentally sustainable

Too often, green revolutions have led to environmental problems that impose high off-site costs and undermine the long-term sustainability of the farming system. Deficient management of modern inputs is the primary cause—a problem exacerbated by inadequate extension and training, ineffective regulation of water quality, and input pricing and subsidy policies that made modern inputs too cheap and encouraged excessive use.

More intensive agriculture is not necessarily inconsistent with good management of the environment—technologies like precision farming, integrated pest management, and improved water management practices can increase yields even while reducing water and chemical use. Reforming policies and institutions so they give farmers incentives to manage inputs sustainably rather than unsustainably remains an unfinished agenda.

Conclusion

In spite of the limitations and criticisms of the Green Revolution, its success in heading off famine in Asia and ensuring the region's long-term food security is undeniable. The increases in food production pulled the region back from the edge of famine. Over the course of 25 years, the region went from suffering food deficits that threatened the lives of millions to producing more food than it could consume. The Asian Green Revolution lifted many people out of poverty, jump-started economic growth, and saved large areas of forest, wetlands, and other fragile lands from conversion to cropland. In short, the investments and policies that underpinned the Green Revolution were highly successful in achieving the objectives of the time. They are a testament to the vision and determination of the many farmers, scientists, and policymakers worldwide who made this "revolution" a reality. ■

NOTES

1. The Green Revolution also stimulated gains in agricultural productivity and production in Latin America, but this chapter focuses on its success in Asia.
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4. Rosegrant, M. W., and P. B. R. Hazell. 2000. *Transforming the rural Asian economy: The unfinished revolution*. Hong Kong: Oxford University Press.
5. Rosegrant and Hazell 2000; Asian Development Bank. 2000. *Rural Asia: Beyond the Green Revolution*. Manila, Philippines: Asian Development Bank.
6. Pinstrup-Andersen, P., and M. Jaramillo. 1986. The impact of technological change on rice production, food consumption, and nutrition in North Arcot, India. Paper presented at the International Food Policy Research Institute/Tamil Nadu Agricultural University "Growth Linkages" workshop, February 14–16, Ootacamund, India.
7. Pinstrup-Andersen, P., and M. Jaramillo. 1991. The impact of technological change in rice production on food consumption and nutrition. In *The Green Revolution reconsidered: The impact of the high yielding rice varieties in South India*, ed. P. B. R. Hazell and C. Ramasamy. India: Johns Hopkins University Press and Oxford University Press.
8. Bouis, H. 2000. Improving human nutrition through agriculture: The role of international agricultural research. *Food and Nutrition Bulletin* 21 (4): 550–66.
9. Rosegrant and Hazell 2000.
10. Asian Development Bank 2000.