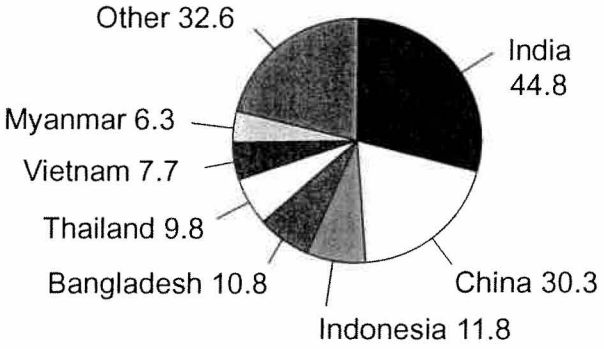
Rice *Oryza sativa*

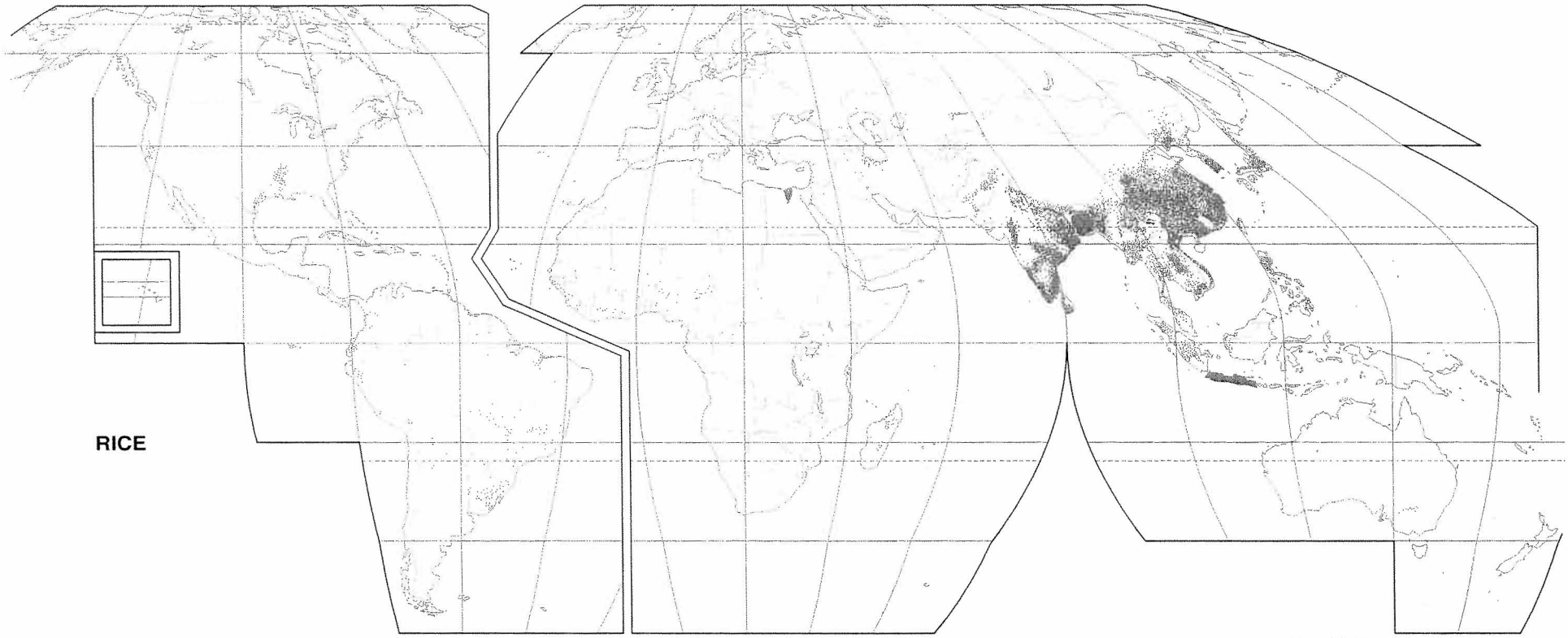
Production	
Area Under Cultivation	154.1 million ha
Global Production	600.6 million MT
Average Productivity	3,897 kg/ha
Producer Price	$176 per MT
Producer Production Value	$105,970 million
International Trade	
Share of World Production	4%
Exports	23.6 million MT
Average Price	$279 per MT
Value	$6,460 million
Principal Producing Countries/Blocs (by weight)	China, India, Indonesia, Bangladesh, Vietnam, Thailand
Principal Exporting Countries/Blocs	Thailand, Vietnam, China, United States, Pakistan, India
Principal Importing Countries/Blocs	Indonesia, Côte d'Ivoire, Iraq, Iran, Saudi Arabia, Nigeria, Brazil, Japan
Major Environmental Impacts	Habitat conversion and biodiversity loss Soil erosion and degradation Agrochemical use Water use and pollution Production of greenhouse gases
Potential to Improve	Good BMPs are known and cost effective Rice is a food security issue, governments will help improve production Genetics (better understood for rice than for other crops) will lead to improved production and reduced impacts

Source: FAO 2002. All data for 2000.

Rice

Area in Production (MMha)





Each dot represents 102,000 MT per year

Chapter 17

Rice

Overview

For most of the world, rice is not only the staff of life but quite literally the stuff of life as well. In many parts of Asia the word for rice literally means food. The Chinese greet each other not by inquiring vaguely "How are you?" but by saying "Have you eaten yet?" It is understood that to eat is to eat rice. A person in China with job security is said to have "an iron rice bowl," while one who has been fired has had his "rice bowl broken". Khush (2000) has noted similar indications of the importance of rice in many Asian countries. In Thai, *khao* means both rice and food. The Emperor in Japan is considered the living embodiment of the ripened rice plant. In Bali it is believed that the God Vishnu caused the Earth to give birth to rice, and the God Indra taught people how to grow and eat it. In the Philippines rice is used at all important rituals. In fact, to show their mourning, relatives do not eat rice for several months after a death in the family (Khush 2000). Rice is not just food in such countries; it is culture.

Traditionally, hundreds or even thousands of rice varieties have had local cultural significance in rice-growing regions. Growing urban populations, however, have forced an increasing emphasis on producing large quantities of a few rice varieties, rather than smaller quantities of many varieties. The result of the "green revolution," is that these new high-yield varieties make more rice available at a lower cost. They also require increased inputs, contrasting sharply with previous cultivation techniques.

It is the demand for rice as a cheap food that is winning out over traditional varieties. Globally, the population of rice consumers is increasing at the rate of 1.7 percent per year compared to overall population growth of 1.3 percent (Khush 2000). Half of the world's projected population of 8 billion in 2025 will be rice consumers. Today, more than a billion rice consumers live in poverty. They have limited access to food and cannot afford to pay any more for rice. All things being equal, to feed these people means that rice production needs to increase by 35 to 40 percent by 2025 yet maintain a stable or even lower price (Khush 2000).

Producing Countries

The Food and Agriculture Organization of the United Nations (FAO) (2002) reports that 114 countries produced rice in 2000. The total amount of land in rice is approximately 154.1 million hectares. More than 90 percent of the world's rice is grown and consumed in Asia. It is grown on about 11 percent of the world's cultivated land (Khush 2000).

The two main rice producers in the world, by area, are India with 44.8 million hectares under cultivation and China with 30.3 million hectares. Also important as major

producers are Indonesia (11.8 million hectares), Bangladesh (10.8 million hectares), Thailand (9.8 million hectares), Vietnam (7.7 million hectares), and Myanmar (6.3 million hectares). These seven countries represent 78.3 percent of the land planted to rice and nearly 81 percent of the 600.6 million metric tons of rice produced globally in 2000. Other significant producers include the Philippines, Brazil, Pakistan, Nigeria, Cambodia, Nepal, the United States, Japan, Madagascar, and Korea (FAO 2002).

Total annual production was estimated at 600.6 million metric tons globally in 2000. This was a world record for production. The main producers by weight are China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, and Japan (FAO 2002).

The FAO (2002) reported that the global average yield in 2000 was 3,897 kilograms per hectare per year. Australia, Egypt, and Greece were the only countries whose average yield exceeded twice that of the rest of the world.

Consuming Countries

Rice provides 23 percent of all the calories consumed by the world's population. This is more than wheat (17 percent) and corn/maize (9 percent). For the low-income populations in Asian countries, however, rice accounts for more than 50 percent of caloric intake. In such countries, the average adult eats about 160 kilograms of milled rice each year, which amounts to about 0.5 kilograms each day (Khush 2000). In the United States, by contrast, rice accounts for less than 2 percent of the per-capita caloric food intake; the average American consumes less than 10 kilograms each year.

Most rice is consumed in the producing country. In 2000 about 23.6 million metric tons, or only 6 percent of global production, was exported. The main exporters are Thailand, Vietnam, China, the United States, Pakistan and India (FAO 2002).

The largest importers are Indonesia, Côte d'Ivoire, Iraq, Iran, Saudi Arabia, Nigeria, Brazil, and Japan (FAO 2002). Depending on the year, China can also be a significant importer. Indonesia imported more rice in 1998 than any other country in history. As a result, the government began to encourage farmers to produce substitutes such as corn, cassava, and sweet potatoes. With the exception of Middle Eastern countries, rice imports shift from country to country each year as local production is reduced by adverse weather and imports are required to supply food needs. Middle Eastern countries must import nearly every year, as local supplies never satisfy demand.

The important thing to remember about rice (and other important sources of calories as well) is that its significance does not derive from feeding subsistence farmers. Rice and other major calorie sources are seen as essential because they feed the urban poor. Put another way, rice feeds the cities of Asia and keeps them politically stable at the same time. The policies of rice-consuming countries are aimed at keeping rice available and affordable.

Production Systems

Rice is grown under a wide range of conditions. It is grown from Australia to Northern China and from below sea level in India to 3,000 meters above sea level in Nepal (Khush 2000). Broadly speaking, there are two main kinds of rice: upland and lowland. Upland rice is characterized by cultivation that utilizes rainfall instead of irrigation. Pesticides, fertilizers, and improved seed varieties may all be used in the production of upland rice. Lowland rice tends to be produced on flat areas with irrigation and an entire package of inputs.

Upland rice is grown on open, often rolling lands. It is rain-fed, and there is no standing water in the rice fields. Depending on the year, it can suffer from prolonged water shortages. Yields average only 1 to 1.5 metric tons per hectare. About 12 percent of all rice land is cultivated as upland rice (Khush 2000).

Lowland rice is further divided into three types: irrigated, flood-prone, and nonirrigated. Most of the land planted to rice—about 55 percent—is irrigated and grown in paddies, and this area produces some 75 percent of all the world's rice. The twentieth-century improvements described below as the "green revolution" dominate irrigated rice production. Because of this technology the average yields for irrigated rice have been raised to 5.5 metric tons per hectare (Khush 2000).

Like irrigated rice, the nonirrigated form of lowland rice is grown in paddies, but it depends on rainfall rather than irrigation. Such fields suffer from both rainfall shortages and excesses. Average yields for this form of cultivation vary from 2 to 2.5 metric tons per hectare. About 25 percent of the world's rice is cultivated this way. Flood-prone rice is grown in the river deltas of Southeast and South Asia. It is produced in standing water of up to a meter. Yields vary from 1.5 to 2 metric tons per hectare. About 8 percent of rice land is cultivated in flood-prone areas (Khush 2000).

Rice cultivation has a long history in Asia. Rice has been grown in paddies since antiquity. The paddies are formed by creating earthen embankments (bunds or dams) around their edges to hold water. The bottom of the fields are made impermeable by puddling, a process in which wet clay is made into an impermeable paste. While this is a good system for producing rice, it makes it very difficult for producers to switch to other crops.

Until recently, Asian rice farmers produced rice cheaply using a buffalo for puddling (unlike tractors, the buffalo is heavy enough to compact the clay but not heavy enough to break through the pan) and manual labor for transplanting, weeding, and harvesting. They were able to produce good yields with few inputs other than water and the sediment it carried. A single hectare could support a family of seven. This picture remained unchanged for centuries; Asia's population and rice production developed at the same speed (Witte, van Elzakker and van Mansvelt 1993).

However, all that changed during the twentieth century. The population began to expand more rapidly, and there was insufficient land for expanding cultivation to support more

people. The situation was aggravated by the fact that urban areas began to grow rapidly, and rural populations began to abandon rice production and move to the cities. For these reasons, rice production was no longer able to keep pace with demand. As a result, new varieties and production systems were needed (Witte, van Elzakker and van Mansvelt 1993).

The new varieties and production systems developed in the twentieth century have come to be known collectively as the green revolution. Rice is probably the best known of the green revolution crops. Green revolution technology consisted of genetic improvements and improved management practices involving use of pesticides and fertilizers, which, when combined, produced higher yields. High-yielding varieties can produce up to 10 metric tons per hectare per crop, but scientists hoped for averages of 5.5 metric tons per hectare per crop (Witte, van Elzakker and van Mansvelt 1993). With irrigation, and the other green revolution inputs such as fertilizer, it was possible to produce up to three crops per year.

Improved rice varieties and technologies developed at the International Rice Research Institute (IRRI) in the Philippines led to major increases in yields. Increases resulted from a variety of factors. Breeding programs increased production and developed shorter rice varieties, which do not waste energy on growth, mature more quickly, and require fewer inputs such as water. Their energy is focused on grain production. These varieties tend to be more susceptible to pests, however, so they are also more dependent on pesticides.

In the 1970s this technology package spread throughout Asia. Government development programs were designed to supply seeds, fertilizers, insecticides, and even water along with the necessary credit to allow farmers to purchase them. Credit was often subsidized to insure that the programs were adopted by farmers. Governments also invested in irrigation schemes, transportation and roads, processing and storage facilities, and extension advice and supervision to make sure that farmers used the green revolution packages correctly (Witte, van Elzakker, and van Mansvelt 1993).

Most of the major rice-growing countries became self-sufficient in rice as a result of the green revolution. Since the first high-yielding rice variety was introduced in 1966, yields increased from 2.1 to 3.7 metric tons per hectare per crop in 1999. Total production increased from 257 million metric tons to 600 million metric tons in 1999, an increase of 134 percent, while the area cultivated increased only 23 percent, from 126 to 155 million hectares (Khush 2000). Moreover, as of 2002 the cost of production was about 20 to 30 percent lower for high-yielding varieties than for traditional ones. The decline in rice production costs and increased overall production have also meant declines in prices, which have benefited the urban poor and landless rural laborers.

The switch to high-yielding rice varieties has contributed to a growth in income of rural landless workers. High-yielding varieties require more labor per unit of land to apply the necessary fertilizers and pesticides as well as to harvest and process the increased output (Khush 2000). Increased employment for rice production also has a multiplier effect, leading to increased overall employment in trade, transportation, construction, and

services in rural areas. The growth of many Asian economies is in part related to growth in agricultural income and its distribution, which expands markets for nonfarm goods.

Despite the major increases in rice production from the green revolution, there are a number of reasons for caution. As a result of changes in U.S. export policy world rice prices plummeted in the 1980s, which affected domestic prices in Asia. Also, the associated lower production costs may not last forever. Green revolution rice has made farmers dependent on fertilizers and pesticides, whose price has tended to increase over time. Due to general economic growth, the price of labor is increasing in many rice-producing areas even as rural poverty increases. And pesticide poisoning is becoming more common for people and the environment.

More importantly, there are fundamental questions regarding whether modern rice production technology is sustainable. As early as 1990 Pingali (as cited in Witte, van Elzakker and van Mansvelt 1993) suggested that green revolution irrigated rice was beginning to show declining yields. The rate of yield decline at the International Rice Research Institute in both the wet and the dry season was 1.28 percent per year, a rate that can seriously undermine the 2 percent per year growth rates achieved through plant breeding during the green revolution. The main causes of production decline appear to be forms of environmental degradation, including increased populations of pests and diseases as well as depletion of soil micronutrients and changes in soil chemistry due to intensive cropping and low-quality irrigation water.

Research in the Philippines suggests that initially only a third of farmers had the management skills to adapt the green revolution technology to their farms. Over time, the ability to understand and manipulate the new technologies on farm has become even more important. A fairly sophisticated level of understanding is required both to implement the current technology and new developments and to solve problems. Producers need to understand tools such as irrigation dynamics and fluctuations, labor or capital availability, technologies to incorporate fertilizers more efficiently, and integrated pest management. As Pingali, Moya, and Velasco wrote, "further productivity gains in the post-green revolution era will come from more efficient use of existing inputs to exploit genetic potential of existing varieties. These 'second generation technologies' are more knowledge intensive and location specific than the modern seed-fertility technology that was characteristic of the green revolution" (1990, as cited in Witte, van Elzakker and van Mansvelt 1993).

It is essential to maintain the current high yields, which will require finding ways to make current production more sustainable. And since there is very little new land to convert to productive rice farming, yields must even be increased on existing areas. This job will be difficult, however, as some of the best rice lands are being lost, water is being diverted to nonfarm uses, and labor is moving to cities (Khush 2000). The way out of this conundrum is through genetic work on varieties with higher yield potential under adverse conditions as well as better management practices. The improved practices will need to focus on integrated nutrient and pest management as well as better water and soil management.

Because rice is such an important staple in many parts of the world, it is a strategic crop. As such, its producers benefit from many subsidies. There are systems of subsidized credit so producers can purchase inputs. In addition to more general subsidies, many countries provide water to rice farmers for free, and several others provide water at far below the actual costs (Witte, van Elzakker and van Mansvelt 1993). Fertilizer, by contrast, is generally taxed rather than subsidized.

Rice production is also affected by a number of other macroeconomic conditions. Bourgeois and Gouyon (2001) offer several insights into how macroeconomic conditions affected both production and profitability before, during, and after the recent Indonesian financial crisis. In the early 1990s, prior to the crisis, the incomes of landowners (producers) grew more slowly than those of urban families, and the income of agricultural laborers actually fell in real terms. Urban areas became more attractive through higher wages, and landowners found it harder to recruit laborers. As a consequence, producers adopted labor-saving practices and technologies, including mechanized rice planting methods (Naylor 1992 as cited in Bourgeois and Gouyon 2001). This increased rural inequity, as not all farmers could afford to invest in or benefit from mechanization. Similarly, landowner farmers—as opposed to renters or sharecroppers—tend to have higher incomes because they do not share the profits from their production. Because of all these factors, small farmers, landless farmers, and agricultural workers had low or zero growth in productivity and declining real incomes prior to the financial crisis.

The economic crisis that began in 1997 had a number of effects on farmers. First, the cost of inputs increased, as these are largely imported, so farmers could no longer invest in fertilizers or pesticides. Without fertilizers, production declined. Potassium in fertilizer boosts pest resistance, so lack of fertilizer also lowered the rice's resistance to pests. Second, because food was scarce, farmers tended to plant rice three times in a year rather than only once or twice, which was a traditional way of limiting the impacts of pests. Finally, farmers planted whenever they could rather than at the same time as their neighbors. This meant that pests could move from one field to another, gathering impact and numbers as they went (Bourgeois and Gouyon 2001).

This problem was accentuated for poor farmers who had to sell their crop at harvest to get immediate cash rather than store it until the price increased. Problems were compounded when they went to buy expensive inputs for the next growing season (Bourgeois and Gouyon 2001). In the end, many farmers shifted to export crops such as cocoa, coffee, shrimp, and spices, where prices in U.S. dollars helped to buoy their income. Depending on the price of rice, such farmers may or may not return to rice cultivation.

What is clear from both these examples is that during periods of economic boom and bust, producers of basic foodstuffs find their economic position slipping. Many personal needs as well as agricultural inputs are more expensive because they are imported or the price is set by international trade. Producers are forced to sell more of their production, more quickly, to buy what they need. Simply put, the price of foodstuffs does not adequately compensate those who produce them.

Processing

Each type of rice has its own unique characteristics and texture. While there are thousands of rice varieties, the main types include white, jasmine, brown, glutinous, short-grained, paddy, black, and red. Each requires somewhat different processing. Within each of these varieties, there are a number of different grades.

The main processing steps for most types of rice include cleaning, husking, separating, milling, grading, and bagging. During cleaning, all foreign objects are removed. These include hay, straw, stones, branches, and—from paddy-grown rice—snail shells. During husking, the excessive husks are cleaned and rubbed off the rice grain. Any remaining husks are separated from brown rice by blowing them from the grain in a process very similar to winnowing other grains. The rice separator catches any unhusked grains remaining in brown rice by applying a difference in gravitational pull and surface friction. The rice with the husk removed is denser and tends to separate from that with husk still on it. The unhusked paddy is then returned to the husking process until its husks are separated. During milling, the outer bran layer is removed from the brown rice and then the bran is separated by air ventilation. White rice is what remains after the bran is removed from brown rice. This process usually takes two to three cycles, depending on the degree of milling required.

Once the clean rice has been milled, it is ready for classification into grades. Grading is the process by which milled rice is separated by size: whole grain, long broken rice (when the broken grain is 75 percent or less of the original grain) and broken. The rice can be further graded by long grain, medium grain or short grain rice (based on length to width ratio). Rice is also graded on transparency (e.g. chalky), color damage (e.g. from insects, heat or water) or foreign matter (e.g. other plant seeds). In addition, the moisture level is measured. Most grading is done mechanically. Finished rice is stored separately according to its grade. After grading, the rice is bagged and is then ready for delivery. Bagging is normally done in units of 1, 5, 10, 15, 25, 45, 50, and 100 kilograms. In some larger markets, rice is sold in bulk by the metric ton. In general, the larger units are defined by the number of 100-kilogram bags. For example, a truckload of rice in many parts of Asia is 140 sacks of 100-kilogram bags, or the equivalent in 1-kilogram, 5-kilogram or 15-kilogram bags.

A by-product of processing is the rice bran, which is removed from the rice kernel in the process of milling white rice. This product is sometimes more expensive by weight than the polished rice itself because of its many uses as a medicinal supplement (e.g. to lower cholesterol and blood pressure and to control some forms of diabetes). It is also a highly sought-after feed ingredient due to its high content of amino acids and proteins.

Most rice is sold in its raw form after the husk and bran have been removed. It is then cooked and eaten directly by people with little more processing. However, rice is also manufactured into a number of different products. These include crackers, noodles, flour, various canned products, milk substitutes, vinegar, and wine. Some rice and residue from processing is used for animal feed.

Product Substitutes

As a source of carbohydrate in many diets, rice is simply one of many possible sources of food for energy. Wheat, corn, sorghum, millet, barley, rye, and other grains are all substitutes. Sweet potato, cassava, and many tubers can be substitutes as well. Tubers, in particular, are more versatile than rice because they can be planted in many types of soils and do not need major landscape transformations (e.g. irrigation works, terracing, etc.) to be produced.

It is important that the politics of food production be shifted to include discussions about crops that have fewer environmental impacts. The main advantage of rice is its versatility in storage and preparation and therefore its convenience for urban consumers. However, on farms and for rural areas, other substitutes are more easily grown and should be encouraged. While substitutes for rice may not store as well or have the same versatility, in rural areas this is not necessarily as important a consideration. Furthermore, a mix of other crops can lead to a more varied, and therefore healthier, diet.

Market Chain

The market chain for rice involves the producer, middlemen, rice mills, brokers, wholesalers, retail shops, and consumers. The price of rice at any point in the chain depends on the total amount of rice available (both from production and in storage) and the relative quality and volume.

The international commerce of rice is controlled by large-scale rice-milling facilities. These large, sunk investments allow companies to achieve economies of scale. These companies tend to dominate the milling in the primary export countries (e.g. Thailand, Vietnam, China, Pakistan, and the United States). Once exported, the rice trade tends to be controlled by the same companies that dominate the international grain trade. Even so, rice is only a small part of grain trade.

For domestic markets and consumption, small mills in many rural areas can be financially viable. These can handle the produce of as little as 200 hectares. Since few small farmers, by definition, produce 200 hectares of rice, most mills in areas dominated by small producers tend to be owned by cooperatives or by the government. Recently there has been a trend in many countries for government-owned mills to be privatized.

Larger mills, by contrast, tend to be integrated with larger production areas as well as more vertically integrated into the market chain. Production from such plants tends to be linked directly to storage, packaging, and distribution systems. These large-scale operations are more common in Thailand, Brazil, Colombia, the United States, and increasingly in Vietnam as well. The destination of rice produced in such systems tends to be for urban consumption and/or for export. In other parts of the world rice distribution is local, neighborhood commerce. Thus, the channels in the market are diverse and based on the capacity for investments along the chain.

Market Trends

Between 1961 and 2000 rice production increased globally by 179 percent and the quantity of rice traded internationally increased by 267 percent (FAO 2002). During the same period, however, the value of rice traded internationally decreased by 61 percent. The increased availability of rice and a decline in the cost of production has contributed to an estimated 40 percent decline in real prices of rice since 1960 on domestic markets. These price declines have benefited the urban poor and the rural landless.

The International Rice Research Institute recently released a report which states that if Asia is to satisfy demand for its growing population over the next thirty years, it will have to increase production by 40 percent or 200 million metric tons by 2030. Such increases will not come from improved genetics alone. Increased production of that magnitude is likely to trigger expansion of cultivation, resulting in larger and larger areas of natural habitat being converted both to upland and paddy-grown rice.

Environmental Impacts

Many of the environmental problems from rice production result specifically from the green revolution rice production technology. This technology has caused significant reductions in biodiversity within rice fields, particularly for paddy-grown rice. However, it also has increased use of fertilizers and pesticides, which in turn has increased pollution of streams, rivers, and groundwater systems through runoff from fields. Rice production also generates more greenhouse gases than any other major agricultural crop. Each of these problems is discussed separately.

Biodiversity Loss within Existing Production Areas

Green revolution rice production technologies have increased production per hectare as well as the number of crops that can be grown successively each year. Clearly these production gains have reduced the habitat conversion that would have had to take place to produce as much rice using the traditional production systems prior to the development of the technology. Even so, green revolution production methods have tended to reduce quite significantly the amount of biodiversity that exists within the production system.

Traditionally, paddy fields are home to many species. Kenmore (1991) writes that "rice ecosystems often have more than 700 animal species per hectare in highly intensified fields in the Philippines and over 1,000 so far described in Asian species of higher trophic level predators and parasitoids." The application of ever-increasing quantities of pesticides and synthetic fertilizers, however, has led to the disappearance of much of this biodiversity, including the beneficial nitrogen-fixing algae whose absence leads to greater dependence on synthetic nitrogen fertilizers. As the agrochemicals affect the microbial life, they also affect the entire food chain that depends on them. Paddies are no longer habitable by the dozens and dozens of species that different farmers harvested for food. In the end, the loss of water reptiles, fish, frogs, and snails deprives people of an important food source.

Current rice production is a monoculture activity undertaken in irrigated paddies. In these production systems, rice varieties are selected on the singular basis of productivity and are further interbred to maximize that trait. This approach has tended to shrink the gene base, and one of the characteristics that is disappearing is pest resistance, which often existed in traditional rice strains. This means that farms increasingly rely on pesticides to do what rice plants were capable of doing in the past.

Pollution from Fertilizers

Synthetic fertilizers affect water quality. For example, nitrogen absorption is quite low in rice production. Estimates from the Philippines suggest that only 30 percent of the applied urea is effectively utilized in rice cultivation. The bulk is lost through volatilization and denitrification. Nitrogen from synthetic fertilizers such as urea is oxidized (through nitrification) into nitrate, which in turn is converted to volatile gaseous forms and lost through denitrification. Losses in the form of ammonia are high, contributing to eutrophication of the paddy water, with a resulting high daytime paddy water alkalinity (Witte, van Elzakker and van Mansvelt 1993).

Phosphorus absorption is even lower. Estimates suggest that not more than 10 to 15 percent of phosphorus added to the soil is absorbed by the crop (Witte, van Elzakker and van Mansvelt 1993). The rest is often transformed to insoluable forms (a process known as phosphorus fixation), and only under certain conditions can these forms be made available to the crop. Inefficient fertilizer use not only costs the farmer money and lowers profits, it also has a polluting effect downstream. Most of these impacts have not been quantified. It is known, however, that nutrient-rich waters coming from agricultural areas in China are a major cause of the frequent red tides along the coast.

Perhaps most important, the repeated and increasing use of synthetic fertilizers also alters the microbial balance that converts organic matter and dissolved minerals in the soil into forms that the rice plant can use. Over time, the reliance of farmers on synthetic fertilizers tends to lead not only to a slow degradation of soil fertility but also to a reduced ability of the soil to absorb chemical inputs.

Pollution from Pesticide Use

Pesticides are perhaps one of the most important environmental problems posed by rice cultivation (Witte, van Elzakker and van Mansvelt 1993) as a result of both their overuse and misuse. Pesticides disrupt healthy ecological processes, as noted above. Equally important, pesticide poisoning is a health issue for both farmers and workers.

Modern rice production uses insecticides, herbicides, molluscicides, and to a small extent fungicides. In the major rice-producing countries of Asia, more agrochemicals are used on rice than on all other crops combined. In the Philippines, for example, 47 percent of all insecticides and 82 percent of all herbicides were used on rice (Witte, van Elzakker and van Mansvelt 1993). In the late 1980s and early 1990s pesticides that had been banned in other countries were still being used in Thailand and the Philippines. These pesticides include chlordane, DBCP, DDT, dinoseb, HCH (hexachlorohexane, better

known as lindane), hexachlorobenzene, methyl parathion, mercury compounds, and PCP (pentachlorophenol). In the Philippines, four pesticides (monocrotophos, methyl parathion, azinphos-methyl, and endosulfan) constituted 70 percent of the pesticides used in rice cultivation in the early 1990s (Witte, van Elzakker and van Mansvelt 1993).

Another impact of the increased use of agrochemical inputs is that many bioaccumulate. This means that people absorb chemicals not only from the rice, but also from other plants, and in concentrated doses from any animals that accumulate the chemicals from what they eat. One survey found that organochlorine insecticides were present in low levels in half of the blood samples taken from Filipino farmers. A report prepared for the Institute of Agricultural Economics in Hanover, Germany, estimates that nearly 40,000 farmers in Thailand suffer from various degrees of pesticide poisoning every year, and that the associated health costs amount to more than U.S.$300,000 per year. The external costs of health care, monitoring, research, regulation, and extension amount to as much as U.S.$127.7 million per year in Thailand alone (*Rice Today* 2002). Studies in Thailand have shown that pesticide residues exist in more than 90 percent of samples of soil, river sediment, fish, and shellfish (*Rice Today* 2002).

One of the problems of restricting or prohibiting the use of pesticides within a country, much less between countries when the products are traded, is to sort out the exact names of the pesticides that are used. Pesticides are often sold under brand names without reference to the chemical compounds included in them. One chemical, for example, is marketed under 296 trade names, another under 274 (*Rice Today* 2002). This makes transparency for users as well as monitoring by governments very difficult.

Production of Greenhouse Gases

There is much speculation about the impact of climate change on the ability of agriculture to feed more people. However, agriculture itself can have a significant effect on global warming through the release of greenhouse gasses. Continuously flooded rice fields, in particular, release methane to the atmosphere (Wassmann et al. 2000). One estimate places methane emissions from rice at some 10 to 15 percent of total global methane emissions (Neue 1993, as cited by Wang et al. 2000). Other estimates suggest that the contribution of rice paddies to global rates of methane emissions ranges from 5 to 30 percent (Minami and Neue 1993, as cited in Witte, van Elzakker and van Mansvelt 1993). Due to the likely continued increase in yields and areas harvested, methane emissions will most likely increase as well.

The processing of rice in large dehuskers leads to the accumulation of large amounts of rice husk waste. This waste is normally burned to reduce the volume and therefore the disposal problem. The burning of waste releases both carbon dioxide and carbon monoxide into the environment.

Water Use

Irrigated rice requires about 1,200 millimeters of water per crop. This amounts to some 5,000 liters per kilogram of rice produced. In some areas water use for rice cultivation

causes salinization of soils, making the land less fertile. Rice is a large and inefficient consumer of water, even by today's agricultural standards. The impacts of the total water withdrawals on biodiversity and ecosystem functions are not well studied. For example, it is not known whether taking water for rice cultivation and reducing flooding during rainy seasons is better or worse for biodiversity than taking water from river systems during the dry season.

The provision of water for rice production causes collateral damage as well. Many dams have been constructed to provide water for the irrigation of rice. These dams prevent migration within freshwater ecosystems and as a result reduce biodiversity. Dams and irrigation systems also increase disease vectors by providing breeding grounds for mosquitoes and other hosts who transmit the diseases where they did not exist before. These can include organisms causing bilharzia (schistosomiasis), malaria, and even diarrhea.

Better Management Practices

There are many different kinds of rice production systems. Fortunately, there are ways to reduce the environmental problems associated with each. However, it now appears that some forms of rice cultivation may be far more productive and yet have fewer innate environmental impacts that would need to be addressed. Since many of these systems are particularly appropriate for smaller producers, they should be investigated and supported not only by those interested in the environment, but also by those interested in food security and poverty reduction.

As with other commodities, it is clear that improved efficiency of input use for rice production can increase yields while reducing costs. There are many ways to improve the efficiency of resource use. These include reducing pesticide and fertilizer use, improving water management, reducing effluents and soil erosion, and improving overall soil management. Many of these improved practices can also reduce the greenhouse gas emissions associated with rice production. Some of the better practices will, in addition, increase wildlife habitat and perhaps even increase producer income streams, as through the sale of hunting permits.

Finally, it is clear that better practices aimed at optimizing certain impacts may in fact contribute negatively to others. Each producer will have to determine which are the most important impacts to be reduced and what are the best ways to accomplish this.

Develop Innovative Production Systems

Rice can be cultivated without paddies and still give yields that are superior to those obtained from paddy culture. It can be irrigated with drip irrigation or overhead sprays in areas where adequate and timely rainfall is not reliable. Rice can be grown in ways similar to vegetable crops and can even be mixed with vegetables and tubers in polyculture systems. New multicrop polyculture technologies could eliminate the need to convert broad areas of land for flooding, which can destroy habitat and local biodiversity

in large regions, uses scarce water resources inefficiently, and can even fail. This perspective is virtually absent from the major rice research institutions, though in fact this "technology" already exists. In Indonesia, Japan, China, and India these types of farming have existed in very old systems for centuries. They can provide insights as well as alternatives to high-input paddy rice cultivation that offer fewer negative environmental impacts.

For example, organic and low-input forms of conventional rice production in Japan and Thailand already demonstrate very high yields. Some produce yields of more than 10 metric tons per hectare per crop and show signs of increasing even more (Hawken et al. 1999). This indicates that environmentally sound practices can produce the improved yields of rice that will be required to feed expanding populations. Other work suggests that additional improvements in rice production can be obtained by interplanting or sequence-planting rice with soybeans, field beans, or other legumes that improve soil fertility and soil biodiversity to improve plant vigor and resilience (Panfilo Tabora, personal communication). These polycultural cropping systems are also vital sources of protein for farmers, both from the plants produced and the wildlife attracted and harbored.

Rice systems contain some of the best-understood community relationships in the tropics. What is not well understood is the relationship of this biodiversity to ecological processes that either increase the viability of lower-input rice production systems or the provision of other marketable items or food for rice cultivators, such as the edible frogs, snails, and fish that have now largely disappeared because of pesticide use.

In China, ecological farming (farming based on the principles of organics combined with modern science and technology to improve yields and quality as well as input use efficiency) is practiced on about 5 percent or less of rice land. Even so the results are interesting. When rice is combined with azolla (an aquatic fern that has symbiotic relationships with nitrogen-fixing cyanobacteria) cultivation, azolla inhibits weed growth and then can be cut as a green manure for the next rice crop. In combining rice cultivation with fish or duck production, 37 to 84 percent of weeds are consumed by either the fish or the ducks. In addition, trials showed that there was a slight increase in soil organic matter with combined rice-and-fish production, plus increases of 16.4 percent, 50 percent, and 9.5 percent in soil levels of phosphorus, potassium, and nitrogen respectively. Levels of dissolved oxygen also improved. Because of the nutrient-rich wastes produced by fish and other animals there are lower quantities of fertilizers and pesticides in the effluent because less of each is used (Chen et al. 1993). Under some types of ecological farming, on 0.2 hectare of land some 1,800 kilograms of rice were produced as well as 130 kilograms of fish. Under traditional green revolution production systems only 1,668 kilograms of rice were produced under normal conditions (Chen et al. 1993).

Paddy rice production obliges changes in topographies that not only include clear-cutting but also changes in hydrology. Such changes are harmful to wildlife. In addition these changes are irreversible without considerable effort and investments when farmers decide to produce different crops. Investments are needed to develop or document technologies

for rice production that are based on respecting topographies and natural features of agricultural sites.

Reduce Pesticide Use

The effect of pesticides on estuaries, rivers, and fragile coastal zones are all reflected in the reduction of fish catch and aquatic biodiversity, as well as species that depend on aquatic biodiversity for food. Reductions in pesticide use will reduce the damage from agriculture on all downstream biodiversity. Data from Thailand and the Philippines suggest that integrated pest management (IPM) can reduce the use of insecticides on rice by 75 to 95 percent. Furthermore, there is no need to use the most toxic categories of pesticides to achieve the same or better results (Witte, van Elzakker and van Mansvelt 1993).

The first recorded implementation of IPM for rice on a massive scale was in Indonesia, where 50,000 farmers were trained in IPM techniques in 1990. Training of farmers was accompanied by the banning of fifty-seven trade formulations of rice insecticides and the introduction of pest-resistant rice varieties. The acreage previously affected by pests such as the brown plant hopper decreased from over 200,000 hectares to below 25,000. In addition, pesticide production in Indonesia dropped from 55,000 metric tons per year to 25,000 metric tons, while rice production increased from 28 million metric tons to 30 million metric tons (Kenmore 1991). It is not clear how much the program cost or whether it was cost-effective.

In the Philippines, by contrast, the costs of IPM training are well documented. IPM program costs are estimated at 230 million pesos per year (the Philippine currency) over five years. Costs per trained farmer are expected to be 500 pesos for the training component only, or 1,150 pesos including management, monitoring, evaluation, and administration. This compares to reduced pesticide costs of approximately 448 pesos per hectare per crop. If two crops of rice are grown annually, this results in a cost recovery in less than one year for the average rice farmer with 1.6 hectares. Another way to look at the expense of the program is that it represents 0.18 percent of the proposed budget for the country's Rice Development Plan. Fertilizer assistance, by comparison, required 12 percent of the same budget (Witte, van Elzakker and van Mansvelt 1993).

In Vietnam, an IPM program reduced insecticide use in the Mekong Delta by an estimated 72 percent. What's more, the number of farmers who believed that insecticides would bring higher yields fell from 83 percent before the IPM campaign to just 13 percent after (*Rice Today* 2002).In China, researchers found that interplanting disease-resistant hybrid rice reduced the severity of the disease known as rice blast by 94 percent and improved the yield of the highly valued glutinous variety by 89 percent (Zhu et al., as cited in *Rice Today* 2002).

Increase Efficiency of Fertilizer Usage

Synthetic fertilizers are expensive, and the volume used in rice production is quite high. Strategies should be pursued to reduce their use while maintaining yields. This will

improve producer profits. There are several ways to increase the efficiency of fertilizer usage. Nitrogen utilization rates, for example, can be improved when it is incorporated into the soil rather than sprayed on the field. This prevents it from volatilizing. Another way to reduce the use of nitrogen by 30 percent or more is to incorporate the rice straw into the soils (Witte, van Elzakker and van Mansvelt 1993). By recycling rice straw through composting and mulching (e.g. basic organic fertilizer strategies), system "leakage" can be reduced considerably, thus minimizing long-term nutrient depletion.

A strategy based on nutrient management practices such as green manuring, the use of azolla, and recycling or composting crop and household wastes can restore soil fertility. The rapid cycle of building up and breaking down organic matter is what builds soil fertility. Such a strategy can limit problems of waste disposal as well as fertilizer costs (Witte, van Elzakker and van Mansvelt 1993). A more efficient use of fertilizer can reduce overall use and can be coupled with the better management practices described above.

Reduce Effluents

Allowing water to stay longer in the rice fields may be a simple way to reduce farm agro-chemicals in runoff. Scientists at the Texas Agricultural Experiment Station have determined how many days water should stand in rice fields to allow breakdown of chemicals to safe levels. For example, some 22.7 kilograms per hectare (20 pounds per acre) of chemicals is the normal chemical content of water runoff from rice fields managed traditionally. If the water is left on the field for five to seven days longer, the level is reduced to 6.8 kilograms per hectare (6 pounds per acre), which is considered safe. In addition, the chemical fertilizers will be available to the roots of the next crop.

Synthetic fertilizers affect water quality, altering the microbial balance that is key to the conversion of organic matter and dissolved minerals into useable form. Water in rice paddies or in settlement ponds can be treated with microbial organic matter that is inoculated with beneficial microorganisms to reestablish its balance either for improved efficiency in the pond or prior to release from the pond.

Improve Water Management

New systems of rice cultivation allow producers to conserve much of the water that was used to cultivate rice thirty years ago. In Australia, for example, more accurate laser siting and leveling of irrigated fields has reduced water use by some 25 percent. Improved control of water movement on and off the land reduces the opportunity for rice pond water to enter the water table from rice fields. Other ways to reduce water use include growing shorter varieties with shorter seasons (meaning they ripen earlier). In Australia, such measures have reduced water use by 30 percent per hectare over the past ten years and increased rice yields 60 percent per water used in the same period.

In California some farmers have begun to employ new recirculating irrigation systems plus automated shutoff valves that conserve up to two-thirds of the water requirements of thirty years ago. Rice fields that are tilled in the fall and left open to drain freely after

each winter rain lose thirty times more soil than rice fields where the stubble is left standing and water is allowed to collect (Ducks Unlimited 2002). Holding soil in the ponds makes downstream freshwater systems cleaner and consequently better wildlife and fisheries habitat. In addition, minimal fall tillage and ponding of winter rainfall promotes the decomposition of rice straw and builds organic matter in the soil. More thoroughly decomposed rice straw means less effort and expenditures at planting time. Maintaining standing water in the winter also appears to suppress germination and growth of winter weeds and thus reduces the work needed for spring field preparation.

Control Erosion and Improve Soil Management

The presence of organic matter in the soil is a key to minimizing soil erosion. However, rice stubble is normally burned or removed because it does not decompose quickly in areas where multiple crops are grown each year. When stubble is incorporated into the soil, its decomposition can release methane gas that damages the roots of subsequent rice crops and reduces productivity. Organic matter can be integrated back into rice fields through the use of effective microorganisms that contribute to a rapid decomposition of the stubble while at the same time trapping the methane and ammonia gases from the decomposition of the stubble and converting them into substances that are useful for plant growth. This system has been used in Japan and China, but it is still not widely adopted (Panfilo Tabora, personal communication).

Reduce Greenhouse Gases

There are several ways to reduce emissions of methane, a greenhouse gas produced in rice paddies. Research has shown that transplanting thirty-day-old seedlings, direct seeding on wet soil, and direct seeding on dry soil reduced methane emissions by 5 percent, 13 percent, and 37 percent, respectively, when compared to transplanting eight-day-old seedlings. Plowing also affects greenhouse gas production. For example, methane emissions following fall plowing were 26 percent less than they were following spring plowing (Ko and Kang 2000).

In addition to reducing rice production's overall contribution to the generation of greenhouse gases, rice fields can sequester some 10 metric tons of carbon per hectare per growing season—but only if crop residue is kept in the soil (Rice Producers of California 2003). If crop residue is burned instead of kept in the soil, the carbon is lost and rice becomes a net contributor to CO_2 production.

Burning rice husks at processing plants is not only harmful environmentally, it is a waste of resources. Rice husks have tremendous value in many greenhouse operations and are in fact bought and transported great distances as a valuable raw material for soil amendments.

Manage Rice Fields as Wildlife Habitat

Rice fields provide considerable food for waterfowl. Even so, this function could be improved considerably with a few rather small changes in management. Where game species are abundant, payments for hunting can increase producer income considerably.

In California, several management changes have improved habitat for wildlife. Earlier flooding of the fields with existing nutrient-rich water has been shown to improve wetland food production for wildlife. Planting and harvesting rice later in the year makes waste grain available to waterfowl when they are migrating. Finally, managing some areas next to rice fields as habitat with natural grasses and sedges provides both cover and food for waterfowl.

Rice fields make excellent stopover points for migratory birds. In California some 95 percent of all wetlands have been lost, greatly reducing available stopover points. In Northern California 500,000 acres of rice fields provide roosting grounds as well as food. The California Rice Straw Burning Reduction Act of 1992 has forced many rice farmers to use winter flooding of rice fields to assist in the decomposition of waste rice straw. This winter flooding in turn has helped provide winter habitat for millions of migratory birds and other wetland species. The fields are a resting ground for an astonishing 3 to 5 million migrating waterfowl every year on the Pacific Flyway and are home to over 141 species of birds, 28 species of animals, and 24 species of amphibians and reptiles. Thirty of these species are listed as endangered, threatened, or species of concern (California Rice Commission 2001).

Outlook

Rice is the most important food crop for people cultivated at this time. A quarter of all the calories consumed by people come from rice, and this figure is 50 percent in Asia. As such, rice is also a strategic crop, one that is extremely sensitive politically. Production in most rice-producing areas is stable or even declining. If all things were equal this would bode ill for those politicians in countries where rice is the staple. But, all things are not equal. In some of the largest rice-consuming countries of the world (China, India, and Indonesia) populations are shifting to cities, where cheap food is not only a food security issue—it is a political survival issue as well. Politicians will be forced to ensure that urban populations have ready supplies of acceptably priced food or they will no longer be in office.

There are ways to produce more rice and to produce it more efficiently. Fortunately, many of these practices would also be more profitable, especially for small farmers. Given that small farmers make up a large proportion of the people that are fleeing the countryside for the cities, it should be possible to find ways to induce them to stay and farm profitably. While this is such an obvious solution, it ultimately will depend on getting the policies and incentives right. This needs to be coordinated not only at a national and local level and with a wide range of different players, but also internationally. Development assistance, research, and even credit need to be used in such a way that they encourage more rational rice production while achieving the scale and efficiency to provide for the needs of urban residents as well. It is not clear if all of this will happen in time.

Resources

Web Resources

www.riceweb.org
www.irri.org
www.warda.cgiar.org/
www.asiarice.org/
agronomy.ucdavis.edu/uccerice/index.htm
www.riceonline.com/home.shtml

Additional resources can be obtained by searching on "rice" on the WWF International Intranet:
http://intranet.panda.org/documents/index.cfm

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References

Bourgeois, R. and A. Gouyon. 2001. From El Niño to Krismon: How rice farmers in Java coped with a multiple crisis. In F. Gerard and F. Ruf. Eds. *Agriculture in crisis: People, commodities, and natural resources in Indonesia, 1996–2000.* Montpellier, France: CIRAD.

California Rice Commission. 2001. California Rice Commission—Environment. Available at http://www.calrice.org/environment/environment.html.

Chen, D., B. Zhong, B. Shen, X. Li, and G. Yu. 1993. *Case study on eco-farming in China with special emphasis on rice.* Geneva, Switzerland: United Nations Conference on Trade and Development. UNCTAD/COM/19. August 27.

Childs, N. 2002. *Rice outlook—U.S. 2001 rice crop pegged at record 213 million hundredweight.* Electronic outlook report from the Economic Research Service. Washington, D.C.: U.S. Department of Agriculture. January 14. RCS 0102. Available at http://www.ers.usda.gov.

——. 2002b. *Rice outlook—U.S. 2001/02 rice imports projected at record 12.5 million hundredweight.* Electronic outlook report from the Economic Research Service. Washington, D.C.: U.S. Department of Agriculture. January 14. RCS 0202. Available at http://www.ers.usda.gov.

——. 2002c. *Rice outlook—U.S. 2001/02 total supplies projected at record 255 million hundredweight.* Electronic outlook report from the Economic Research Service. Washington, D.C.: U.S. Department of Agriculture. January 14. RCS 0302. Available at http://www.ers.usda.gov.

Ducks Unlimited. 2002. Rice industry caring for the environment. Available at http://www.ducks.org/conservation/rice_soil_conservation.asp.

FAO (Food and Agriculture Organization of the United Nations). 2002. *FAOSTAT statistics database.* Rome: UN Food and Agriculture Organization. Available at http://apps.fao.org.

Greenland, D. J. 1997. *The sustainability of rice farming.* CAB International and IRRI (International Rice Research Institute).

Hawken, P., A. Lovins, and L. H. Lovins. 1999. *Natural capitalism: Creating the next industrial revolution.* Boston: Little, Brown and Company.

Kenmore, P. E. 1991. *Indonesia's integrated pest management: A model for Asia.* Manilla: FAO Inter-Country Program for Integrated Pest Control in Rice in South and Southeast Asia.

Khush, G. S. 2000. Rice: How much it takes to feed half the world's population. Paper presented at the 2000 meeting of the American Association for the Advancement of Science (AAAS). San Francisco, Calif.

Ko, J. Y. and H. W. Kang. 2000. The effects of cultural practices on methane emission from rice fields. *Nutrient Cycling in Agroecosystems.* 58:3113–14. The Netherlands: Kluwar Academic Publishers.

Naylor, R. 1992. Labour-saving technologies in the Javanese rice economy: Recent developments and a look into the 1990s. *Bulletin of Indonesian Economic Studies* 28(3): 71–91.

Pingali, P.L. 1992. Diversifying Asian rice-farming systems: A deterministic paradigm. In Barghouti, S., L. Garbux and D. Umali. 1992. *Trends in agricultural*

diversification: Regional perspectives. World Bank Technical Paper No. 180. Washington, D.C.:World Bank.

Rice Producers of California. 2003. Environmental issues. Available at http://www.riceproducers.com/environment.html. Accessed 2003.

Rice Today. 2002. Pesticide misuse. 1(1) April:10–11. International Rice Research Institute. Available at http://www.irri.org.

Runge, F. 1994. *The grains sector and the environment: Basic issues and implications for trade.* Rome: U.N. Food and Agriculture Organization.

Smil, V. 2000. *Feeding the world: A challenge for the twenty-first century.* Cambridge, Mass.: MIT Press.

USA Rice Federation. 2001. *Environmental advantages of rice.* Rice Online Environmental Information. Available at http://www.riceonline.com/environ.htm. Arlington, VA.: USA Rice Federation.

Wang, Z. Y., Y. C. Xu, Z. Li, Y. X. Guo, R. Wassman, H. U. Neue, R. S. Lantin, L. V. Buendia, Y. P. Ding, and Z. Z. Wang. 2000. A four-year record of methane emissions from irrigated rice fields in the Beijing region of China. *Nutrient Cycling in Agroecosystems.* 58:53–63. The Netherlands: Kluwar Academic Publishers.

Wassmann, R., H. U. Neue, R. S. Lantin, L. V. Buendia, and H. Rennenberg. 2000. Characterization of methane emissions from rice fields in Asia. *Nutrient Cycling in Agroecosystems.* 58:112. The Netherlands: Kluwar Academic Publishers.

Witte, R., B. van Elzakker and J. D. van Mansvelt. 1993. *Rice and the environment: Environmental impact of rice production, policy review and options for sustainable rice development in Thailand and the Philippines.* UNCTAD/COM/22.

Zhu, Y., H. Chen, J. Fan, Y. Want, Y. Li, J. Chen, J. X. Fan, S. Yang, L. Hu, H. Leung, T. W. Mew, P. S. Teng, Z. Wang, and C. C. Mundt. 2000. Genetic diversity and disease control in rice. *Nature* 406 (August 17):718–722.London: Macmillan.