CHALLENGES IN FEEDING THE WORLD IN THE 21ST CENTURY[1/]

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Introduction

It is a pleasure to visit once again the University of Nuevo Leon and the progressive city of Monterrey. I am now in my 56th year of continuous involvement in agricultural research and production in the low-income, food-deficit developing countries. Over these five decades, I have worked with many colleagues, political leaders, and farmers to transform lower-yielding food production systems into higher-yielding ones.

World Food Production Challenges

In 1998 global food production of all types stood at 5.03 billion metric tons of gross tonnage and 2.48 billion tons of edible dry matter (Table 2). Of this total, 99% was produced on the land—only about 1% came from the oceans and inland waters. Plant products constitute 92 percent of the human diet, with about 30 crop species providing most of the world's calories and protein, including eight species of cereals, which collectively account for 70 percent of the world food supply. Animal products, constituting 8 percent of the world's diet, also come indirectly from plants.

Had the world's food supply been distributed evenly, it would have provided an adequate diet in 1998 (2,350 calories, principally from grain) for 6.9 billion people—about 900 million more than the actual population. However, had people in Third World countries attempted to obtain 70% of their calories from animal products—as in the USA, Canada, or EU countries—a world population of only 2.8 billion people could have been sustained—less than half of the present world population.

These statistics point out two key problems of feeding the world's people. The first is the complex task of producing sufficient quantities of the desired foods to satisfy needs, and to accomplish this Herculean feat in environmentally and economically sustainable ways. The second task, equally or even more daunting, is to distribute food equitably. <u>Poverty</u> is the main impediment to equitable food distribution, which, in turn, is made more severe by rapid population growth.

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Table 2. World Food Supply, 1998

Commodity	Production, million metric tons Gross Tonnage	Edible Matter[1]	Dry Protein[1]
Cereals	**2,072**	**1,725**	**172**
Maize	613	539	56
Wheat	589	519	61
Rice	577	391	33
Barley	139	122	12
Sorghum/millet	89	80	7
Roots & Tubers	**652**	**174**	**11**
Potato	299	65	8
Sweet potato	139	42	2
Cassava	162	60	1
Legumes, oilseeds, oil nuts	**162**	**110**	**38**
Sugarcane & sugar beet[3]	**152**	**152**	**0**
Vegetables & melons	**615**	**72**	**6**
Fruits	**430**	**59**	**3**
Animal products	**951**	**188**	**83**
Milk, meat, eggs	830	157	63
Fish	121	31	22
All Food	**5,034**	**2,480**	**313**

1/ Zero moisture content, excluding inedible hulls and shells.
2/ Sugar content only.

Source: FAOSTAT, 1999

Projected World Food Demand

During the first decade of the 21st Century, world population is likely to grow by another one billion people. A medium projection is for world population to reach about 8.3 billion by 2025, before hopefully stabilizing at about 10-11 billion toward the end of the 21st Century.

At least in the foreseeable future plants—and especially the cereals—will continue to supply virtually all of our increased food demand. Even if current per capita food consumption stays constant, population growth would require that world food production increases by 2.6 billion gross tons—or 57 percent—between 1990 and 2025. However, if diets improve among the destitute hungry, estimated to be 1 billion people living mainly in

Asia and Africa, world food demand could double—to 9 billion gross tons—over this 35-year period.

Using population growth rates shown above, and expected changes in per capita cereal demand, we have come up with following cereal production projections through the year 2025 (Table 3), and the requisite yield increases needed if we assume that virtually all of the increased production will come from existing farmlands.

Table 3. Current and Projected World Cereal Production and Demand (million tons) and Yield Requirements

	Actual Production		Projected Demand	Yield t/ha Actual		Required
	1990	2000	2025	1990	2000	2025
Wheat	600	740	1,200	2.4	2.8	4.4
Rice	520	640	1,030	2.4	3.1	5.3
Maize	480	620	1,070	3.7	4.1	5.8
Barley	180	220	350	2.3	2.7	4.1
Sorghum/millet	85	110	180	1.5	1.8	2.6
All Cereals	**1,970**	**2,450**	**3,970**	**2.5**	**2.9**	**4.5**

Source: FAO Production Yearbook and author's estimates

Water Resources—The Need for a "Blue Revolution"

One of the greatest challenge facing humankind is how to continue expanding food production in the face of growing water shortages. Water shortages and pollution are causing widespread public health problems, limiting economic growth and agricultural development, and harming a wide range of ecosystems. They may put global food supplies in jeopardy, and lead to economic stagnation in many areas of the world.

Although water covers about 70 percent of the Earth's surface only about 2.5 percent is fresh water. Moreover, most of the Earth's fresh water is frozen in the ice caps of Antarctica and Greenland, in soil moisture, or in deep aquifers not readily accessible for human use. Indeed, less than 1 percent of the world's freshwater—that found in lakes, rivers, reservoirs, and underground aquifers shallow enough to be tapped economically—is readily available for direct human use (World Meteorological Organization, 1997).

Agriculture accounts for 93 percent of the global consumptive use of water. Rainfed agriculture, covering 83 percent of the world's farmland, accounts for about 60 percent of global food production. Irrigated agriculture—which accounts for 70 percent of global water withdrawals—covers some 17 percent of cultivated land and contributes contributes nearly 40 percent of world food production (Table 1).

Table 1. World Irrigated Agricultural Area (1000 ha)

	1961	1970	1980	1990	1997
World	**138,813**	**167,335**	**209,265**	**243,028**	**267,729**
Regions/Selected Countries					
Dev'ing Asia	**87,000**	**105,859**	**128,961**	**151,397**	**172,055**
China	30,402	38,113	45,467	47,965	51,890
India	24,685	30,440	38,487	45,144	57,000
Pakistan	10,751	12,950	14,680	16,940	17,580
Latin America	**8,130**	**9,999**	**13,598**	**16,182**	**18,334**
Argentina	980	1,280	1,580	1,680	1,700
Brazil	490	796	1,600	2,700	3,169
Chile	1,075	1,180	1,255	1,265	1,270
Colombia	226	250	400	680	1,061
Mexico	3,000	3,583	4,980	5,600	6,500
Peru	1,016	1,106	1,160	1,450	1,760
Africa	**6,556**	**7,426**	**8,279**	**9,853**	**11,044**
Egypt	2,568	2,843	2,445	2,648	3,300
Madagascar	300	330	645	1,000	1,090
Morocco	875	920	1,217	1,258	1,251
Sudan	1,480	1,625	1,800	1,946	1,950
Developed Countries	**37,036**	**44,050**	**58,426**	**65,615**	**66,291**
Australia	1,400	1,476	1,500	1,832	2,700
France	360	539	870	1,300	1,670
Italy	2,400	2,400	2,400	2,711	2,692
Japan	2,940	3,415	3,055	2,846	2,701
South Africa	808	1,000	1,128	1,290	1,270
Spain	1,950	2,379	3,029	3.402	3,603
Romania	206	731	2,301	3,109	3,089
USA	14,000	16,000	20,582	20,900	21,400
USSR	9,400	11,100	17,200	20,800	19,843*

* Sum of former Soviet Union republics
Source: FAOSTAT, 1999

The UN's 1997 Comprehensive Assessment of the Freshwater Resources of the World estimates that, "about one third of the world's population lives in countries that are experiencing moderate-to-high water stress, resulting from increasing demands from a growing population and human activity. By the year 2025, as much as two-thirds of the world's population could be under stress conditions. Mexico, I am sad to report, is one of those nations facing the greatest potential water shortages in the coming decades.

The world irrigated has doubled between 1961 and 1996—from 139 to 268 million ha. In most of these schemes, proper investments were not made in drainage systems to maintain water tables from rising too high and to flush salts that rise to the surface back down through the soil profile. We all know the consequences—serious salinization of many irrigated soils, especially in drier areas, and waterlogging of irrigated soils in the more humid area. In particular, many Asian irrigation schemes—which account for nearly two-thirds of the total global irrigated area—are seriously affected by both problems. The result is that most of the funds going into irrigation end up being used for stopgap maintenance expenditures for poorly designed systems, rather than for new irrigation projects. Government must invest in drainage systems in ongoing irrigation schemes, so that the current process of salinization and waterlogging is arrested.

The inevitable conclusion is that humankind in the 21st Century will need to bring about a "Blue Revolution" to complement the so "Green Revolution" of the 20th Century. Water use productivity must be wedded to land use productivity. Science and technology will be called upon to show the way.

In new irrigation schemes, water drainage and removal systems should be included in the budget from the start of the project. Unfortunately, adding such costs to the original project often will result in a poor return on investment. Society then will have to decide how much it is willing to subsidize new irrigation development.

There are many technologies for reducing water use. Wastewater can be treated and used for irrigation. This could be an especially important source of water for peri-urban agriculture, which is growing rapidly around many of the world's mega-cities. Water can be delivered much more efficiently to the plants and in ways to avoid soil waterlogging and salinization. Changing to new crops requiring less water (and/or new improved varieties), together with more efficient crop sequencing and timely planting, can also achieve significant savings in water use.

Proven technologies, such as drip irrigation, which saves water and reduces soil salinity, are suitable for a much larger area than currently used. Various new precision irrigation systems are also on the horizon, which will supply water to plants only when they need it. There is also a range of improved small-scale and supplemental irrigation systems to increase the productivity of rainfed areas, which offer much promise for smallholder farmers.

Clearly, we need to rethink our attitudes about water, and move away from viewing it as nearly a free good, and a God-given right. Pricing water delivery closer to its real costs is a necessary step to improving use efficiency. Farmers and irrigation officials (and urban consumers) will need incentives to save water. Moreover, management of water distribution networks, except for the primary canals, should be decentralized and turned over to the farmers. Farmers' water user associations in the Yaqui valley in northwest Mexico, for example, have done a much better job of managing the irrigation districts than did the Federal Ministry of Agriculture and Water Resources previously.

Future Crop Research Challenges

Agricultural researchers and farmers, worldwide, face the challenge during the next 25 years of developing and applying technology that can increase the cereal yields by 50-75%, and to do so in ways that are economically and environmentally sustainable. Much of the yield gains will come from applying technology "already on the shelf". But there will also be new research breakthrough, especially in plant breeding to improve yield stability and, hopefully, maximum genetic yield potential.

Genetic improvement—Continued genetic improvement of food crops—using both conventional as well as biotechnology research tools—is needed to shift the yield frontier higher and to increase stability of yield. In rice and wheat, three distinct, but inter-related strategies are being pursued to increase genetic maximum yield potential: changes in plant architecture, hybridization, and wider genetic resource utilization (Rajaram and Borlaug, 1996; Pingali and Rajaram, 1997). Significant progress has been made in all three areas. IRRI remains optimistic that it will be successful in developing the new "super rice," with fewer—but highly productive—tillers. While still probably 10-12 years away from widespread impact on farmers' fields, IRRI claims that this new plant type, in association with direct seeding, could increase rice yield potential by 20-25% (Kush, 1995).

In wheat, new plants with an architecture similar to the "super rices" (larger heads, more grains, fewer tillers) could lead to an increase in yield potential of 10-15% above the spring x winter ***Veery*** descendants (Rajaram and Borlaug, 1997). Introducing genes from related wild species into cultivated wheat—can introduce important sources of resistance for several biotic and abiotic stresses, and perhaps for higher yield potential as well, especially if the synthetic wheats are used as parent material in the production of hybrid wheats (Kazi and Hettel, 1995).

The success of hybrid rice in China (now covering more than 50 percent of the irrigated area) has led to a renewed interest in hybrid wheat, when most research had been discontinued for various reasons. However, recent improvements in chemical hybridization agents, advances in biotechnology, and the emergence of the new wheat plant type make it increasingly likely that the yield frontier can be increased by 25-30 percent.

Maize production has really begun to take off in many Asia countries, especially China. It now has the highest average yield of all the cereals in Asia, with much of the genetic yield potential yet to be exploited. Moreover, recent developments with high-yielding quality protein maize (QPM) varieties and hybrids stand to improve the nutritional quality of the grain without sacrificing yields. This achievement—which was delayed nearly a decade because of inadequate funding—offers important nutritional benefits for livestock and humans. With biotechnology tools, it is likely that we see a range of nutritional "quality" improvements incorporated into the cereals in years to come.

There is growing evidence that genetic variation exists within most cereal crop species for genotypes that are more efficient in the use of nitrogen, phosphorus, and other plant nutrients than are currently available in the best varieties and hybrids. In addition, there is good evidence that further heat and drought tolerance can be built into high-yielding germplasm.

Crop management—Crop productivity depends both on the yield potential of the varieties and the crop management employed to enhance input and output efficiency. Crop management productivity gains can be made all along the line—in tillage, water use, fertilization, weed and pest control, and harvesting.

An outstanding example of water saving technology in wheat production is the "bed planting system," which has multiple advantages over conventional planting systems. Plant height and lodging are reduced, leading to 5-10% increases in yields and better grain quality. Water use is reduced 15-20 percent, and input efficiency (fertilizers and crop protection chemicals) is also greatly improved, which permits total input reduction by 30 percent.

Already adopted in widely in northwest Mexico and growing in acceptance in other countries, Shandong Province and other parts of China are now preparing to extend this technology rapidly (personal communications, Prof. Xu Huisan), President, Shandong Academy of Agricultural Science, July 7, 1999).

Conservation tillage (no-tillage, minimum tillage) is spreading rapidly in the agricultural world. The Monsanto Company estimated that there were 75.3 million ha using conservation tillage in 1996 and this area is projected to grow to 95.5 million ha by the year 2000 (Monsanto 1997 Annual Report).

Conservation tillage offers many benefits. By reducing and/or eliminating the tillage operations, turnaround time on lands that are double- and triple-cropped annually can be significantly reduced, especially rotations like rice/wheat and cotton/wheat. This leads to higher production and lower production costs. Conservation tillage also controls weed populations and greatly reduces the time that small-scale farm families must devote to this backbreaking work.

What Can We Expect from Biotechnology?

During the 20th Century, conventional breeding has produced a vast number of varieties and hybrids that have contributed immensely to higher grain yield, stability of harvests, and farm income. There has been, however, important improvements in resistance to diseases and insects, and in tolerance to a range of abiotic stresses, especially soil toxicities, but we also must persist in efforts to raise maximum genetic potential, if we are to meet with the projected food demand challenges before us.

What began as a biotechnology bandwagon nearly 20 years ago has developed invaluable new scientific methodologies and products which need active financial and organizational support to bring them to fruition in food and fiber production systems. So far, biotechnology has had the greatest impact in medicine and public health. However, there are a number of fascinating developments that are approaching commercial applications in agriculture. In animal biotechnology, we have Bovine somatatropin (BST) now widely used to increase milk production, and Porcine somatatropin (PST) waiting in the wings for approval.

Transgenic varieties and hybrids of cotton, maize, potatoes, containing genes from ***Bacillus thuringiensis,*** which effectively control a number of serious insect pests, are now being successfully introduced commercially in the United States. The use of such varieties will greatly reduce the need for insecticide sprays and dusts. Considerable progress also has been made in the development of transgenic plants of cotton, maize, oilseed rape, soybeans, sugar beet, and wheat, with tolerance to a number of herbicides. This can lead to a reduction in overall herbicide use through much more specific interventions and dosages. Not only will this lower production costs; it also has important environmental advantages.

Good progress has been made in developing cereal varieties with greater tolerance for soil alkalinity, free aluminum, and iron toxicities. These varieties help to ameliorate the soil degradation problems that have developed in many existing irrigation systems. They will allow agriculture to succeed in rainfed, acid-soil areas, such as the ***Cerrados*** in Brazil and in central and southern Africa, thus adding more arable land to the global production base. Greater tolerance of climatic extremes such as drought, heat, and cold, will benefit irrigated areas in several ways. First, we will be able to achieve "more crop per drop" through designing plants with reduced water requirements and adoption of between crop/water management systems Recombinant DNA techniques can speed up the development process.

The development of transgenic plants for the control of viral and fungal diseases is not nearly so developed, but it is only a matter of time. Already, there are some promising examples of specific virus coat genes in transgenic varieties of potatoes and rice that confer considerable protection. Other promising genes for disease resistance are being incorporated into other crop species through transgenic manipulations.

The majority of agricultural scientists—myself included—anticipate great benefits from biotechnology in meeting the food and fiber needs of the 21st Century. However, since most of this research is being done by the private sector, which patents its inventions, agricultural policy makers must face up to a potentially serious problem. How will these resource-poor farmers of the world be able to gain access to the products of biotechnology research? How long, and under what terms, should patents be granted for bio-engineered products? Further, the high cost of biotechnology research is leading to a rapid consolidation in the ownership of agricultural life science companies. Is this desirable? These issues are matters for serious consideration by national, regional and global governmental organizations.

Still, national governments need to be prepared to work with—and benefit from—the new breakthroughs in biotechnology. First and foremost, government must establish a regulatory framework to guide the testing and use of genetically modified crops. These rules and regulations should be reasonable in terms of risk aversion and cost effective to implement. Let's not tie science's hands through excessively restrictive regulations. Since much of the biotechnology research is underway in the private sector, the issue of intellectual property rights must be addressed, and accorded adequate safeguards by national governments.

Standing up to the Anti-Science Crowd

Science and technology are under growing attack in the affluent nations where misinformed environmentalists claim that the consumer is being poisoned out of existence by the current high-yielding systems of agricultural production. While I contend this isn't so, I often ask myself how it is that so many supposedly "educated" people are so illiterate about science? There seems to be a growing fear of science, per se, as the pace of technological change increases. The breaking of the atom and the prospects of a nuclear holocaust added to people's fear, and drove a bigger wedge between the scientist and the layman. The world was becoming increasingly unnatural, and science, technology and industry were seen as the culprits. Rachel Carson's ***Silent Spring***, published in 1962, reported that poisons were everywhere, killing the birds first and then humans—struck a very sensitive nerve.

Of course, this perception was not totally unfounded. By the mid 20th century air and water quality had been seriously damaged through wasteful industrial production systems that pushed effluents often literally into "our own backyards." Over the past 30 years, we all owe a debt of gratitude to environmental movement in the industrialized nations, which has led to legislation to improved air and water quality, protect wildlife, control the disposal of toxic wastes, protect the soils, and reduce the loss of biodiversity.

Yet, in almost every environmental category—at least in the developing world—far more progress is being made than most in the media are willing to admit—at least in the industrialized world. Why? I believe that it's because "apocalypse sells." Sadly, all too many scientists, many who should and do know better, have jumped on the environmental bandwagon in search of research funds.

When scientists align themselves with anti-science political movements, like the anti-biotechnology crowd, what are we to think? When scientists lend their names to unscientific propositions, what are we to think? Is it any wonder that science is losing its constituency? We must be on guard against politically opportunistic, pseudo-scientists like T.D. Lysenko, whose bizarre ideas and vicious persecution of anyone who disagreed with him, contributed greatly to the collapse of the former USSR.

I often ask the critics of modern agricultural technology what the world would have been like without the technological advances that have occurred? For those whose main concern is protecting the "environment," let's look at the positive impact that the application of science-based technology has had on the land.

Had Asia's 1961 average cereal yields (930 kg/ha) still prevailed today, nearly 600 million ha of additional land—of the same quality—would have been needed to equal the 1997 cereal harvest (milled rice adjusted) (Figure 1). Obviously, such a surplus of land was not available in populous Asia. Had we brought more marginal and fragile land into food production, think of soil erosion, loss of forests and grasslands, wildlife species that would have become extinct had we tried to produce these larger harvests with the old lower-input technology!

In his writings, Professor Robert Paarlberg, who teaches at Wellesley College and Harvard University in the United States, has sounded the alarm about the consequences of the debilitating debate between agriculturalists and environmentalists over what constitutes so-called "sustainable agriculture" in the Third World. This debate has confused—if not paralyzed—many in the international donor community who, afraid of antagonizing powerful environmental lobbying groups, have turned away from supporting science-based agricultural modernization projects still needed in much of smallholder Asia, sub-Saharan Africa, and Latin America. This deadlock must be broken.

We cannot lose sight of the enormous job before us to feed 10-11 billion people, most of who will begin life in abject poverty. Only through dynamic agricultural development will there be any hope to alleviate poverty and improve human health and productivity.

Farmers need to be motivated to adopt many of the desired improvements in input use efficiency (irrigation water, fertilizers, crop protection chemicals). This will require a two-pronged-strategy, in which reductions in subsidies are linked to aggressive and effective extension education programs to increase the efficiency of input use. Universal primary education is imperative for rural boys and girls—and must be given the highest priority. Ways must also be found to improve access to information by less-educated farmers to facilitate their accelerated adoption of the newer "environmentally friendly" production technologies.

Closing Comments

Thirty years ago, in my acceptance speech for the Nobel Peace Prize, I said that the Green Revolution had won a temporary success in man's war against hunger, which if fully implemented, could provide sufficient food for humankind through the end of the 20th century. But I warned that unless the frightening power of human reproduction was curbed, the success of the Green Revolution would only be ephemeral.

I now say that the world has the technology—either available or well advanced in the research pipeline—to feed a population of 10 billion people, without destroying the environment. The more pertinent question today is whether farmers and ranchers will be permitted to use this new technology?

However, extreme environmental elitists seem to be doing everything they can to stop scientific progress in its tracks. Small, well-financed, vociferous, and anti-science groups are threatening the development and application of new technology, whether it is developed from biotechnology or more conventional methods of agricultural science.

I agree fully with a petition drafted by Professor C.S. Prakash of Tuskegee University, and now signed by several thousand scientists in support of agricultural biotechnology that: "No food products, whether produced with recombinant DNA techniques or more traditional methods, are totally without risk. The risks posed by foods are a function of the biological characteristics of those foods and the specific genes that have been used, not of the processes employed in their development."

Even with the power of biotechnology to develop food crop varieties with higher yield potential, greater efficiency in the use of water and plant nutrient, and enhanced nutritional quality, unless soil fertility in restored and maintained—especially in the low-income developing world—these genetic advances will not achieve the potential of these genotypes. Chemical fertilizer is the fuel that will power their forward thrust.

Lest I be misunderstood, let me say that farmers need to use all of the available organic sources of plant nutrients, including animal and human wastes, green manures, and crop residues. But even with full utilization of these so-called "organic fertilizers" they will not be nearly enough. Indeed, to replace the roughly 90 million metric tons of chemical nitrogen fertilizer, we would to need to increase the roughly 1.5 billion cattle that we have in the world today to 6-7 billion head, with all of the feeding and waste collection implications that such an increase would entail.

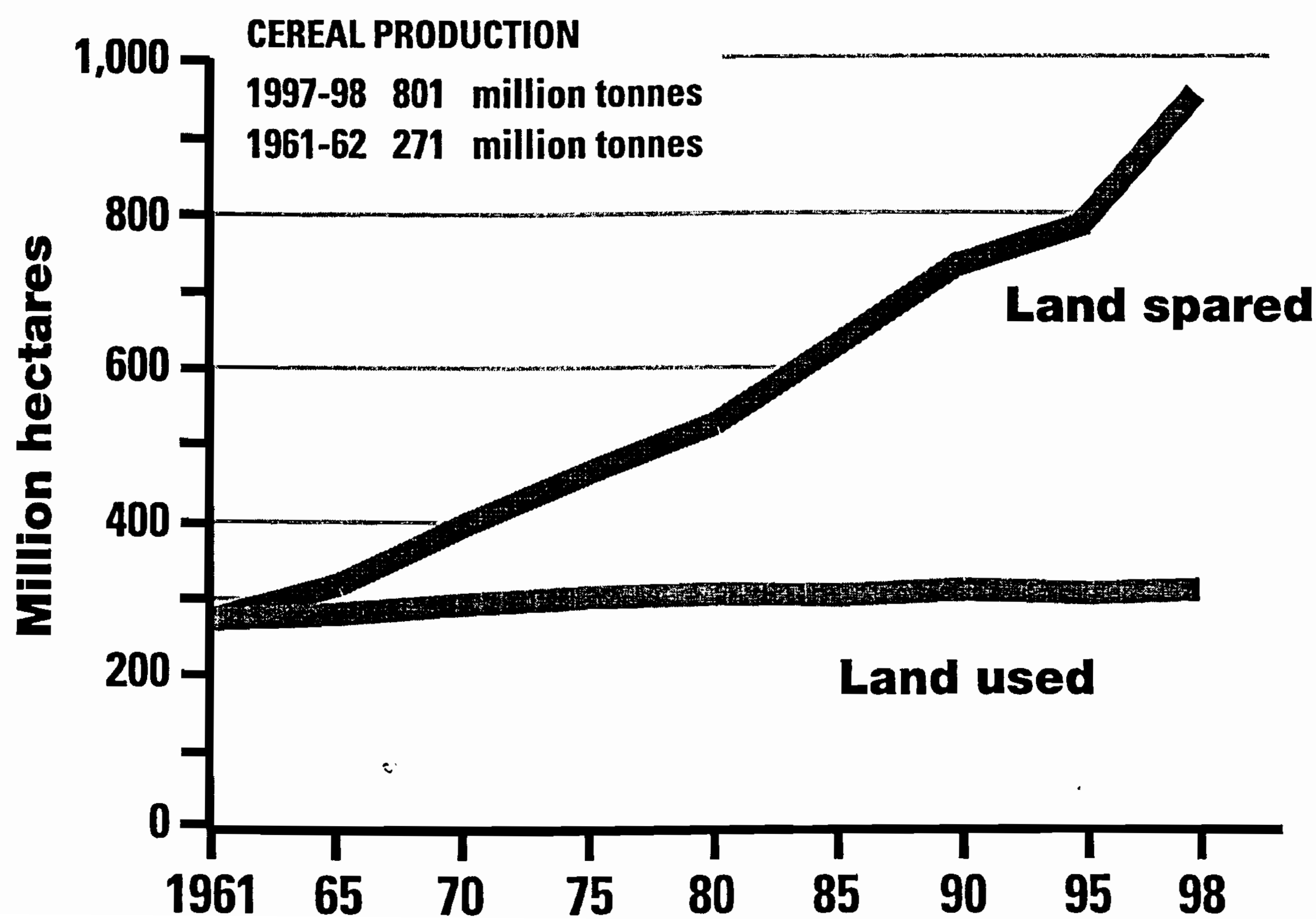
University of Manitoba Professor Vaclav Smil, a world expert on nitrogen cycles estimates that about 40 percent of today's 6 billion people are alive, thanks to the Haber-Bosch process of synthesizing ammonia, which is the feedstock for nitrogen fertilizers. Without this essential product of science and technology, at least 2.4 billion people would perish. With food demand likely to double again in the next 50 years, we can say with certainty that our dependence on chemical fertilizers—especially in those low-income developing countries where fertilizer use is still quite low—will rise significantly during the next two generations.

While the affluent nations can certainly afford to pay more for food produced by the so-called "organic" methods, the one billion chronically undernourished people of the low-income, food-deficit nations cannot. Only through significant labor productivity improvements can agricultural poverty be reduced. Fortunately, these increases in income will permit farmers to make more resource conservation investments. As the Kenyan archeologist

Richard Leakey likes to reminds his environmental supporters, "you have to be well-fed to be a conservationist!"

Most certainly, agricultural scientists and leaders have a moral obligation to warn the political, educational, and religious leaders about the magnitude and seriousness of the arable land, food and population problems that lie ahead. If we fail to do so in a forthright manner, we will be negligent in our duty and inadvertently will be contributing to the pending chaos of incalculable millions of deaths by starvation. The problem will not vanish by itself; to continue to ignore it will make a future solution more difficult to achieve.

Fig. 1. **Cereal Production in Asia—Area Spared Through the Adoption of Improved Technology**



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