AGRICULTURE IN THE 21ST CENTURY VISION FOR RESEARCH AND DEVELOPMENT IN ASIA

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Introduction

It is a pleasure to visit southeast Asia again, to participate with scientists and national policy makers in discussions about the prospects and future of biotechnology in Thailand and the Philippines. The majority of agricultural scientists—myself included—anticipate great benefits from biotechnology in the coming decades to help meet our future food and fiber needs. Indeed, the commercial adoption by farmers of transgenic crops has been one of the most rapid cases of technology diffusion in the history of agriculture. Between 1996 and 1999, the area planted commercially to transgenic crops has increased from 1.7 to 39.9 million hectares (James, 1999).

I am now in my 56th year of continuous involvement in agricultural research and production in the low-income, food-deficit developing countries. I have worked with many colleagues, political leaders, and farmers to transform lower-yielding food production systems into higher-yielding ones.

Great progress has been achieved in Asian agriculture since the early 1960s (FAOSTAT, 1998). Between 1961 and 1998, cereal production in Developing Asia has increased more than three-fold, due largely to the widespread adoption during the 1960s and 1970s of high-yielding rice and wheat production technology (and later in maize and other crops). The core technological components were management-responsive varieties, fertilizers, and irrigation.

Poverty Still Haunts Asia

Despite the successes of smallholder Asian farmers in applying Green Revolution technologies to triple cereal production since 1961, the battle to ensure food security for hundreds of million miserably poor Asian people is far from won, especially in South Asia. Of the roughly 1.3 billion people in this sub-region, 500 million live on less than US$ 1 per day, 400 million are illiterate adults, 264 million lack access to health services, 230 million to safe drinking water, and 80 million children under 4 are malnourished (***Eliminating World Poverty***. UK White Paper, 1997). Mushrooming

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populations and inadequate poverty intervention programs have eaten up many of the gains of the Green Revolution.

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. Poverty is the main impediment to equitable food distribution, which, in turn, is made more severe by rapid population growth.

Future Food Demand

IFPRI's 2020 projections indicate that Asian cereal demand (for food and feed) will increase considerably, both because of expected population growth and rising incomes (Rosegrant, et. al., 1995).

Most Asian societies today are still primarily rural, with more than half their labor forces engaged in agriculture. But the region is urbanizing rapidly, at roughly twice the rate of national population growth. In a number of countries non-farm employment (rural and urban) already exceeds agricultural employment. By the year 2020 most Asian countries are likely to have more people living in urban centers than in rural areas.

Higher incomes and urbanization are leading to major changes in dietary patterns. While per capita rice consumption is declining wheat consumption is increasing in most Asian countries, an indication of rising incomes and westernization of diets (Pingali and Rosegrant, 1998). Per capita consumption of fish, poultry and meat products is on the rise., and this expanding poultry and livestock demand will, in turn, require growing quantities of high quality feeds to supply its needs.

The migration of rural Asians to urban areas will affect farm production in several ways. First, with an out-migration of labor, more farm activities will have to be mechanized to replace labor-intensive practices of an earlier day. Second, large urban populations, generally close to the sea, are likely to increasingly buy food from the lowest-price producer, which for certain crops may very well mean importing from abroad. Domestic producers, therefore, will have to compete—in price and quality—with these imported foodstuffs.

Production Potential

Total cereal production (milled rice equivalent used) in the developing Asian nations has increased from 248 to 795 million tonnes between 1961 and 1998. During this period, most Asian countries achieved—or nearly achieved—food self-sufficiency in the basic grains. During the next 20 years, Asian farmers will have to meet this current level of production plus produce several hundred million additional tonnes of cereals more than they do today. Even with significant new production growth, Asian wheat imports, for example, are likely to increase from 30 to 75 million tonnes by 2020 (Pingali and Rosegrant, 1998).

Over the past 35 years, FAO reports that in Developing Asia the irrigated area has nearly doubled—to 169 million nutrient hectares, and fertilizer consumption has increased more than 30-fold over, and is now stands at about 70 million tonnes of nutrients. During the next century, Asia's food supply will be produced on a shrinking land base. While there are still opportunities to bring irrigation to some new lands, rainfed agriculture will become increasingly more important for expanding future supplies of cereals. Here, the spread of modern varieties in rainfed areas has begun is growing rapidly. (Morris and Byerlee, 1998).

Most Asian farmers have adopted modern varieties. HYVs already cover almost all of the irrigated rice and wheat areas, and a fair portion of the rainfed areas. But varietal replacement is too slow, with farmers often only changing varieties (with the exception of India) every 10 years or so. There are important gains to be made from more rapid varietal replacement, in which farmers have early access to the newer varieties with higher yield potential and resistance to a greater range of biotic and abiotic stresses.

There is still considerable scope to increase cereal yields, especially in rainfed areas but also in many irrigated areas as well. Significant increases in 'technical efficiency' are possible by using more purchased inputs and capital to substitute for increasingly scarce land and labor (Byerlee, 1992). Among the growing proportion of farmers who already have achieved high cereal yields, the interest in using more precise information and management skills to improve the efficiency of input use, mainly to reduce production costs.

Future Crop Research Challenges

Agricultural researchers and farmers in Asia face the challenge during the next 25 years of developing and applying technology that can increase the cereal yields by 50-75 percent, and to do so in ways that are economically and environmentally sustainable. Much of the near-term yield gains will come from applying technology "already on the shelf". But there will also be new research breakthroughs—especially in plant breeding to improve yield stability and, hopefully, maximum genetic yield potential—if science is permitted to work as it should be.

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 percent (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 reason, mainly low heterosis which trying to exploit cytoplasmic male sterility, and high seed production costs. However, recent improvements in chemical hybridization agents, advances in biotechnology, and the emergence of the new wheat plant type have made an assessment of hybrids worthwhile. With better heterosis and increased grain filling, the yield frontier of the new plant material could be 25-30 percent above the current germplasm base.

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 the 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 new Green/Blue Revolution 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 percent increase in yields and better grain quality. Water use is reduced 15-20 percent, a spectacular savings! Input efficiency (fertilizers and crop protection chemicals) is also greatly improved, which permits total input reduction by 25 percent. After growing acceptance in Mexico and 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). Think of the water use and water quality implications of such technology!!

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 (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 reduce the time that small-scale farm families must devote to this backbreaking work. Finally, the mulch left on the ground reduces soil erosion, increases moisture conservation, and builds up the organic matter in the soil—all very important factors in natural resource conservation.

Water Resource Development

Water covers about 70 percent of the Earth's surface. Of this total, only about 2.5 percent is fresh water. 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). This only represents about 0.007 percent of all the water on Earth!

Agriculture accounts for 93 percent of the global consumptive use of water (rainfall and irrigation). 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 (about 270 million ha) and contributes nearly 40 percent of world food production.

How can we continue to expand food production for a growing world population within the parameters of likely water availability? The inevitable conclusion is that humankind in the 21st Century will need to bring about a "Blue Revolution—more crop for every drop" 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.

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” (WMO, 1997).

“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.”

The world irrigated area—with of it located in Asia—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. 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 thinking of 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.

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 will help to ameliorate the soil degradation problems that have developed in many existing irrigation systems. They will also allow agriculture to succeed into 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 abiotic 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.

There are also hopeful signs that we will be able to improve fertilizer use efficiency as well. Scientists from the University of Florida and the Monsanto company have been working on the development through genetic engineering of wheat and other crops that have high levels of glutamate dehydrogenase (GDH). Transgenic wheats with high GDH, for example, yielded up to 29 percent more with the same amount of fertilizer than did the normal crop (Smil, 1999).

Transgenic plants that can control of viral and fungal diseases are not nearly so developed. Nevertheless, 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.

Recently, IRRI scientists, in collaboration with other researchers, have succeeded in transferring genes to increase the quantity of Vitamin A, iron, and other micronutrients contained in rice. This could have profound impact for millions of people with deficiencies ofVitamin A and iron, causes of blindness and aenemia, respectively.

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.

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 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. Moreover, even if it were available, think of soil erosion, loss of forests and grasslands, wildlife species that would have ensured had we tried to produce these larger harvests with the low-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, many—indeed probably most—of whom 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. Many agricultural research and extension organizations need to be decentralized, more strongly farmer-oriented, and more closely linked within the technology-generation and dissemination process. Universal primary education in rural areas—for both boys and girls—is imperative and must be given the highest priority. Ways must also be found to improve access to information by less-educated farmers—because of equity reasons and also to facilitate accelerated adoption of the newer knowledge-intensive 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. The more pertinent question today is whether farmers and ranchers will be permitted to use this new technology?

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 written by Professor C.S. Prakash of Tuskegee University, and now signed by several thousand scientists worldwide, in support of agricultural biotechnology, which states 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."

While the affluent nations can certainly afford to adopt elitist and positions, and pay more for food produced by the so-called "natural" methods, the one billion chronically undernourished people of the low-income, food-deficit nations cannot. It is access to new technology that will be the salvation of the poor, and not, as some would have us believe, maintaining them wedded to outdated, low-yielding, and more costly production technology.

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, even with breakthroughs in biotechnology. If we fail to do so, we will be negligent in our duty and inadvertently may be contributing to the pending chaos of incalculable millions of deaths by starvation. But we must also speak to policy makers—unequivocally and convincingly—that global food insecurity will not disappear without new technology; to ignore this reality will make future solutions all the more difficult to achieve.

REFERENCES

Byerlee, D. 1992. Technical change, productivity, and sustainability in irrigated cropping systems of South Asia: Emerging issues in the post-Green Revolution era. *Journal of International Development 4(5)*: 477-496.

Byerlee, D. 1996. Knowledge-Intensive Crop Management Technologies: Concepts, Impacts, and Prospects in Asian Agriculture. ***International Rice Research Conference***, Bangkok, Thailand, 3-5 June, 1996.

James, Clive. 1999. Global Review of Commercialized Transgenic Crops: 1999. ISAAA Briefs No.12 Preview. ISAAA:Ithaca, NY>

Khush, G.S. 1995. Modern varieties—their real contribution to food supply and equity. *Geojournal* 35(3), 275-284.

Morris, M. and D.Byerlee. 1998. "Maintaining Productivity Gains in Post-Green Revolution Asian Agriculture. *In* International Agricultural Development 3rd Edition, Eds:Carl K. Eicher and John Staatz. Johns Hopkins University Press,: Baltimore and London.

Mujeeb-Kazi, A., and G.P. Hettel, eds. 1995. Utilizing Wild Grass Biodiversity in Wheat Improvement—15 Years of Research in Mexico for Global Wheat Improvement. Wheat Special Report No. 29. Mexico, DF:CIMMYT.

Pingali, P.L. and S. Rajaram. 1997. "Technological Opportunities for Sustaining Wheat Productivity Growth,": paper presented at the World Food and Sustainable Agriculture Program Conference:***Meeting the Demand for Food in the 21st Century: Challenges and Opportunities for Illinois Agriculture***, Urbana, Illinois, May 27, 1997.

Rajaram, S. and N.E. Borlaug. 1997. "Approaches to Breeding for Wide Adaptation, Yield Potential, Rust Resistance and Drought Tolerance," paper presented at ***Primer Simposio Internacional de Trigo***, Cd. Obregon, Mexico, April 7-9, 1997.

Rosegrant, M.W., Mercedita Agcaoili-Sombilla, and Nicostrato D. Perez. 1995. Global Food Projections to 2020. Washington DC:IFPRI.

Smil, Vaclav. 1999. Long-Range Perspectives on Inorganic Fertilizers in Global Agriculture. Travis P. Hignett Memorial Lecture, IFDC, Muscle Shoals, Alabama

United Kingdom. 1997. Eliminating World Poverty: A Challenge for the 21st Century. White Paper presented to Parliament by the Secretary of State for International Development.

World Meteorological Organization. 1997. Comprehensive Assessment of the Freshwater Resources of the World.