Chapter 48

How to Feed the 21st Century?

The Answer is Science and Technology

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INTRODUCTION

It is a pleasure to participate in this International Symposium on the Genetics and Exploitation of Heterosis in Crops, the first meeting of its kind, I understand, in the last 47 years.

I am now in my 53rd year of continuous involvement in food production programs in developing nations. During this period, I have seen much progress in increasing the yield and production of various crops, especially the cereals, in many food-deficit countries. Clearly, the research that backstopped this progress has produced huge returns. Yet, despite a more than tripling in the world food supply during the past three decades, the so-called Green Revolution in cereal production has not solved the problem of chronic under nutrition for hundreds of millions of poverty-stricken people around the world who are unable to purchase the food they need, despite its abundance in world markets, due to unemployment or underemployment.

The invention of agriculture, some 10 000 to 12 000 years ago, heralded the dawn of civilization. It began with rainfed, hand-hoe agriculture, which evolved into an animal-powered, scratch-tooled agriculture, and finally into an irrigated agriculture along the Euphrates and Tigris rivers that for the first time allowed humankind to produce food surpluses. This permitted the establishment of permanent settlements and urban societies which, in turn, engendered culture, science and technology. The rise and fall of ancient civilizations in the Middle East and Meso-America were directly tied to agricultural successes and failures, and it behooves us to remember that this axiom still remains valid today.

ORIGINS OF FOOD CROP SPECIES

We will never know with certainty when nature first began inducing genetic diversity, making recombinations, and exerting selection pressure on the progenitors of the plant species that would be chosen much later by man as his food crop species. But as the Mesolithic Age gave way to the Neolithic there suddenly appeared, in widely dispersed regions, the most highly successful group of plant and animal breeders that the world has ever seen—the Neolithic domesticators. Within a relatively short geological period, apparently only 20 to 30 centuries, Neolithic man, or more probably woman, domesticated all of the major cereals, grain legumes, root crops, and animal species that remain to this day as humankind's principal sources of food.

Agriculture and animal husbandry spread rapidly from their cradles of origin across vast areas of Asia, Africa, Europe, and the Americas. These migratory diffusions were in large part possible because of the tremendous genetic diversity that existed in the original land races and populations of the domesticated crop plants. This genetic variability permitted—with the aid of continued mutations, natural hybridizations, and recombination of genes—the spinning off of new genotypes that were suitable for cultivation in many environments.

The groundwork for genetic improvement of crop plant species by scientific man was laid by Darwin in his writings on the variation of life species (published in 1859) and through Mendel's discovery of the laws of inheritance (reported in 1865). Darwin's book immediately generated a great deal of interest, discussion, and controversy; however, Mendel's discovery was largely ignored at first. Nearly 40 years transpired before these two strands of scientific though were joined by Carl Correns, Erich Von Tschermak, and Hugo De Vries, in independent studies. This rediscovery of Mendel's laws in 1900 provoked a tremendous scientific interest in genetics. The fact that Mendel had worked out his principals on a plant [the sweet pea (*Pisum sativum* L.)] encouraged many to prepare themselves for a career in applied plant genetics.

It was recognized early on that inbreeding leads to reduced vigor in the following generation and that vigor can be restored by crossing. Darwin noted this phenomenon in The Vegetable Kingdom, published in 1876. The first organized attempt to exploit hybrid vigor in maize (*Zea mays* L.) was initiated by W.J. Beal at Michigan State College in 1875. Beal's work and that of other stimulated little interest for 25 years until Edward East and George Shull proved conclusively that although maize lost vigor on inbreeding, when inbred lines were crossed, the progeny of the next generation exhibited an explosive recovery of vigor called heterosis. A few years after I was born, Donald Jones, an associate of Edward East, figured out a solution to the high seed cost of hybrids, with the development of the double-cross hybrid.

But there was no stampede to exploit this potential until the mid 1920s when H.A. Wallace, later to become Secretary of Agriculture and Vice President under Franklin Roosevelt, founded Pioneer Hi-Bred, the first private hybrid seed company. Because of the disastrous economic depression of the 1930s, the use of hybrids did not really take off until the early 1940s. But by the mid-1950s, hybrids dominated U.S. maize production and the use of open-pollinated varieties had virtually disappeared.

Since the commercial introduction of the first hybrids in the USA some 50 plus years ago, many improved elite, double-, three-way and single-cross hybrids have been developed with continually higher yields, improved disease and insect resistance, and shorter and stronger stalks. During this period, average U.S. yields have increased from 1.8 to 8.2 t ha^{-1}, a phenomenal 4.5-fold increase.

Tremendous genetic improvement for yield and yield dependability also has been achieved in wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.), barley (*Hordeum vulgare* L.), and other cereals, grain legumes, roots and tubers, sugarcane, (*Saccharum officinarum* L.) fruits and vegetables, and the fiber and tree crops.

During the past seven decades, 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. Surprisingly, there has been no major increase in the maximum genetic yield potential of the high-yielding semidwarf wheat and rice varieties commercially being grown since those that served to launch the so-called Green Revolution of the 1960s and 1970s. There have been, however, important improvements in resistance to diseases and insects, and in tolerance to a range of abiotic stresses, especially soil toxicities. But we must also find new and appropriate technology to raise genetic yield levels higher, if we are to cope with the food production challenges before us. I'll say more about this later in this chapter.

Of course, plant breeding, or genetic improvement, has been only one component of the total research effort to improve—in the case mentioned above—maize production. Research and development efforts in soil fertility, weed science, and pest management have also led to the development of high- analysis mineral fertilizers and effective crop protection chemicals, which have permitted the new management-responsive varieties to express their genetic yield potential. And research and development in farm machinery has allowed the farmer to increase enormously his labor productivity.

OUR WORLD FOOD SUPPY

In 1994, global food production of all types stood at 4.74 billion metric tons of gross tonnage and 2.45 billion tons of edible dry matter (Table 48–1). Of this total, 99% was produced on the land. Only about 1% came from the oceans and inland waters, even though 70 percent of the earth's surface is covered with water. Plant products constituted 93% of the human diet, with about 30 crops species providing most of the world's calories and protein, including eight species of cereals, which collectively accounted for 66% of the world food supply. Animal products, constituting 7% of the world's diet, also come indirectly from plants.

Had the world's food supply been distributed evenly, it would have provided and adequate diet in 1994 (2350 calories, principally from grain) for 6.4 billion people—about 800 million more than the actual population. However, had

Table 48–1. World food production, 1994. Source: 1994 FAO Production Yearbook.

	Production, million metric tons			
Commodity	Gross tonnage	Edible matter†	Dry protein†	Increase, % 1980–1992‡
Cereals	1950	1623	162	22
Maize	570	501	52	19
Wheat	528	465	55	22
Rice	535	363	31	35
Barley	161	141	14	7
Sorghum/millet	87	78	7	7
Roots & Tubers	583	156	10	9
Potato	265	58	6	3
Sweet potato	124	37	2	7
Cassava	152	56	1	24
Legumes, oilseeds, oil nuts	387	263	88	48
Sugarcane and sugarbeet §	133	133	0	21
Vegetables and melons	486	57	5	32
Fruits	388	53	2	28
Animal products	858	170	75	25
Milk, meat, eggs	760	143	57	21
Fish	98	25	18	29
All Food	4743	2456	343	24

† At zero moisture content, excluding inedible hulls and shells.
‡ 1979–1981 and 1989–1991 averages used to calculate changes.
§ Sugar content only.

people in Third World countries attempted to obtain 30% of their calories from animal products—as in the USA, Canada, or EEC countries—a world population of only 2.6 billion people could have been sustained—less than one-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 in environmentally and economically sustainable ways. The second task, equally or even more daunting than the first, is to distribute food equitably. Here, poverty is the main impediment to equitable food distribution, which, in turn, is made more severe by rapid population growth.

PROJECTED WORLD FOOD DEMAND

During the 1990s, world population will grow by nearly one billion people and then again by another one billion people during the first decade of the 21st Century. A medium projection is for world population to reach 6.2 billion by the year 2000, 8.3 billion by 2025, 10 billion by 2045, before hopefully stabilizing at 11 to 12 billion toward the end of the 21st Century.

At least in the foreseeable future we will continue to relay on plants and especially the cereals, to supply virtually all of our increased food demand. Even if current per capita food consumption stays constant, population growth will require that world food production increases by 2.6 billion gross tons between 1994 and 2025. However, if diets improve among the destitute, estimated to be 1 billion people living mainly in Asia and Africa, world food demand could increase by 100 percent—from 4.7 to nearly 9 billion gross tons—during this period. It will have to increase by another 5 billion gross tons between 2025 and 2045. Let me summarize. World food production has to double over the next 30 years and triple over the next 50 years.

Raising Yield Levels on Existing Agricultural Lands

While there are still some vast areas to bring into production in South America and Africa, much of the projected increases in food supply will have to come from land currently in production. Fortunately, there are many improved agricultural technologies—already available or well advanced in the research pipeline—that can be employed in future years to raise crop yields, especially in the low-income food deficit countries where most of the hunger and poverty exist.

Yields can still be increased by 50 to 100% in much of the Indian sub-Continent, Latin America, the former USSR and Eastern Europe, and by 100 to 200% in much of sub-Saharan Africa, providing political stability is maintained, bureaucracies that destroy entrepreneurial initiative are reigned in, and researchers and extension workers devote more energy to putting science and technology to work at the farm level. Yield gains in China and industrialized North America and Western Europe will be much harder to achieve, since they are already at very high levels. Still, I am hopeful that scientific breakthroughs—particularly from genetic engineering, will permit another 50% increase in yields over the next 25 years.

The most frightening prospect of food insecurity is found in sub-Saharan Africa, where the number of chronically undernourished could rise to several hundred million people if current trends of declining per capita production are not reversed. Sub-Saharan Africa's increasing population pressures and extreme poverty; the presence of many human diseases, e.g., malaria, tuberculosis, river blindness, trypanosomiasis, guinea worm aids, etc.; poor soils and uncertain rainfall; changing ownership patterns for land and cattle; inadequacies of education and public health systems; poorly developed physical infrastructure; weaknesses in research and technology delivery systems will all make the task of agricultural development very difficult.

Despite these formidable challenges, many of the elements that worked to bring a Green Revolution to parts of Asia and Latin America during the 1960s and 1970s also will work in sub-Saharan Africa. An effective system to deliver modern inputs—seeds, fertilizers, crop protection chemical—and to market output must be established. If this is done, Africa can make great strides toward improving the nutritional and economic well-being of Africa's downtrodden farmers, who constitute more than 70 percent of the populations in most countries.

Since 1986, I have been involved in food crop production technology transfer projects in sub-Saharan Africa spearheaded by the Nippon Foundation and its former Chairman, the late Mr. Ryoichi Sasakawa, and enthusiastically supported by former U.S. President Jimmy Carter. Our joint program is known as Sasakawa-Global 2000, and it currently operates in 12 African countries: Ghana, Benin, Togo, Nigeria, Tanzania, Ethiopia, and most recently, in Mozambique, Guinea, Burkina Faso, Mali, Uganda, and Eritrea. Previously, we also operated similar projects in Sudan and Zambia.

The heart of these projects are dynamic field testing and demonstration programs for major food crops. Although improved technology—developed by national and international research organizations—had been available for more than a decade, for various reasons it was not being adequately disseminated among farmers. Working in concert with national extension services during the past 10 years, more than 600 000 demonstration plots (usually from 0.25 to 0.5 ha) have been grown by small-scale farmers. Most of these plots have been concerned with demonstrating improved basic food crops production technology for maize, sorghum, wheat, cassava, and grain legumes. The packages of recommended production technology include: (i) the use of the best available commercial varieties or hybrids, (ii) proper land preparation and seeding dates and rates to achieve good stand establishment, (iii) proper application of the appropriate fertilizers, including green manure and animal dung, when available, (iv) timely weed control and, when needed, crop protection chemicals, (v) moisture conservation and/or better water use, if under irrigation.

Virtually without exception, the yields obtained by participating farmers on these demonstration plots are two to three times higher—and occasionally four times higher—than the control plots employing traditional methods. Only rarely have plot yields failed to double that of the control. Hundreds of field days attended by tens of thousands of farmers have been organized to demonstrate and explain the components of the production package. In project areas, farmers' enthusiasm is high, and political leaders are now taking much interest in the program. From our experiences over the past decade, I am convinced that if there is political stability, and if effective input supply and output marketing systems are developed including a viable agricultural credit system, the nations of sub-Saharan Africa can make great strides in improving the nutritional and economic well-being of their desperately poor populations.

Bringing New Lands into Production: the Remaining Frontiers

Most of the opportunities for opening new agricultural land to cultivation have already been exploited (Table 48–2). This is certainly true for densely populated Asia and Europe. Only in sub-Saharan Africa and South America do large unexploited tracts exist, and only some of this land should eventually come into agricultural production. But in populous Asia, home to half of the world's people, there is very little uncultivated land left to bring under the plow. Apparently in West Asia there are already some 21 million hectares being cultivated that shouldn't be. Most likely, such lands are either too arid, or, because of topography, so vulnerable to erosion that they should be removed from cultivation.

Table 48–2. Potential cropland (million ha) in the less developed countries. Source: Calculated from Buringh and Dudal (1987) Table 2.6, p. 22, World Bank.

	Africa	West Asia	S/SE Asia	East Asia	South America	Central America	Total
Potentially cultivated	789	48	297	127	819	75	2155
Presently cultivated	168	69	274	113	124	36	784
Uncultivated	621	0	23	14	695	39	1392
% of region	79	0	8	11	85	52	NA
% all regions	29	0	1	0.5	32	2	65

One of the last major land frontiers are the vast acid-soils areas found in the Brazilian ***cerrado*** and ***llanos*** of Colombia and Venezuela, central and southern Africa, and in Indonesia. Historically bringing these unexploited potentially arable lands into agricultural production posed what were thought to be insurmountable challenges. But thanks to the determination of interdisciplinary teams in Brazil and international research centers, the prospects of making many acid soil savanna areas into productive agricultural areas has become a viable reality.

Let's look briefly at the Brazilian ***cerrado***. The central block, with 175 million hectares in one contiguous area, forms the bulk of the savanna lands. Approximately 112 million hectares of this block is considered potentially arable. Most of the remainder has potential value for forest plantations and improved pastures for animal production. The soils of this area are mostly various types of deep loam to clay-loam latosols (oxisols, ultisols), with good physical properties, but highly leached of nutrients by Mother Nature in geologic time, long before humankind appeared on the planet. These soils are strongly acidic, have toxic levels of soluble aluminum, with most of the phosphate fixed and unavailable.

In pre-colonial times, the area was sparsely inhabited by a number of Amerindian tribes dependent on a culture based on hunting and gathering of wild plants. During the colonial period, and continuing from Independence up until about 35 years ago, the ***cerrado*** was considered to be essentially worthless for agriculture (except for the strips of alluvial soils along the margins of streams, which were less acidic and where there had been an accumulation of nutrients). The natural savanna/brush flora of poor digestibility and nutritive quality—resulting in low carrying capacity—was used for extensive cattle production.

Through a slow painful process over the past 50 years, involving some outstanding scientists, bits and pieces of research information and new types of crop varieties have been assembled. Only during the past 20 years have these pieces been put together into viable technologies and applied by pioneering farmers. By the end of the 1980s Brazil's national research corporation, EMBRAPA, and several international agricultural research centers (especially CIMMYT and CIAT), have developed a third generation of crop varieties combining tolerance to aluminum toxicity with high yield, better resistance to major diseases, and better agronomic type. These included rice, maize, soybeans (*Glycine max* Merr.), wheat, and several species of pasture grasses, including the panicums, pangola, and brachiaria. Triticale (× *Triticosecale* Wittmack) is an interesting man-made cereal that has a very high level of aluminum tolerance, although it has not been used much yet either for forage or for grain production.

Table 48–3. Potential food production if available technology is adopted on *Cerrado* area already in production. Source: Prospects for the Rational Use of the Brazilian ***Cerrado*** for Food Production by Jamil Macedo, CPAC, EMBRAPA, 1995.

Land use	Area	Productivity	Production
	million ha	t ha^{-1} y^{-1}	million T
Crops (rainfed)	20.0	3.2	64
Crops (irrigated)	5.0	6.0	30
Meat (pasture)	20.0	0.2	4
Total	45.0		98

Improved crop management systems were also developed, built around liming, fertilizer to restore nutrients, crop rotations and minimum-tillage that leave crop residues on the surface to facilitate moisture penetration and reduce run off and erosion. However, with conservation tillage coming into widespread use, it will be absolutely necessary to work out better crop rotations to minimize the foliar disease infections that result from inoculum in the plant crop residues left on the surface from previous seasons.

In 1990, roughly 10 million hectares of rainfed crops were grown in the ***cerrado***, with an average yield of 2 t ha^{-1} and a total production of 20 million tons. The irrigated areas are still relatively small with an average yield of 3 t ha^{-1} and a total production of 900 000 tons. There are also 35 million hectares of improved pasture supporting an annual meat production of 1.7 million tons. During the 1990s the area using improved technology has expanded greatly. If it continues to spread, farmers could attain 3.2 t ha^{-1} in rainfed crops and 64 million tons of production. If the irrigation potential is developed. which can add another 30 million tons of food production, it is likely that by 2010 ***cerrado*** food production will have increased to 98 million tons—or a four-fold increase over 1990 (Table 48–3).

WHAT CAN WE EXPECT FROM BIOTECHNOLOGY?

I am now convinced that what began as a biotechnology bandwagon some 15 years ago has developed some 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 USA. 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 herbicide use by much more specific dosages and interventions.

The development of transgenic plants for the potential control of viral and fungal diseases is also picking up considerable speed. There are some very promising examples of specific virus coat genes in transgenic varieties of potatoes, rice, and vegetables that confer considerable protection. Other promising genes for disease resistance are being incorporated into other transgenic crop species.

Until recently, it has been generally assumed that increases in genetic yield potential in plants (and animals) are controlled by a large number of genes, each with small additive effects; however, the work of recent years shows that there may also be a few genes that are sort of master genes that affect the interaction, either directly or indirectly, of several physiological processes that influence yield. For example, BST and PST are apparently such master genes. They not only affect the total production of milk or meat, but also the efficiency of production per unit of feed intake. It now appears that the dwarfing genes, Rht1 and Rht2, used to develop the high-yielding Mexican wheats that launched the Green Revolution, also acted as master genes, for at the same time that they reduced plant height and improved standability, they also increased tillering and the number of fertile florets and the number of grain per spike (harvest index). Biotechnology may be a new window through which to search for new master genes for high yield potential by eliminating the confounding effects of other genes.

CAN AGRICULTURAL SCIENCE STAY AHEAD OF WORLD POPULATION GROWTH?

So far, agricultural research and production advances—and the efforts of the world's farmers—have kept food production ahead of aggregate world population changes. However, there can be no lasting solution to the world food-hunger-poverty problem until a more reasonable balance is struck between food production/distribution and human population growth. The efforts of those on the food-production front are, at best, a holding operation which can permit others on the educational, medical, family planning, and political fronts to launch an effective, sustainable, and humane attack to tame the population monster.

Still, there is a crying need today for creative pragmatism in research and extension organizations in many parts of the developing world. In particular, we need more venturesome young scientists who are willing to dedicate their lives to helping to solve the production problems facing several billion small-scale farmers. In seeking to push forward the frontiers of scientific knowledge, some researchers often lose sight of the most pressing concerns of farmers and cease to develop products that extension workers can promote successfully. In the low-income developing countries, impact on farmers' fields should be the primary measure by which to judge the value of this research work, rather than by a flood of publications that often serve to enhance the position of the scientist but do little to alleviate hunger.

A growing number of agricultural scientists, myself included, anticipate great benefits from biotechnology in meeting our future food and fiber needs. Since most of this research is being done by the private sector, which patents its inventions, those of us concerned with agricultural policy must face up to a potentially serious conundrum. Most of those being born into this world are among the abject poor, most of whom live in rural areas of the developing world, and who depend on low-yielding agricultural production systems to eke out a meager existence. How will these resource-poor farmers be able to afford the products of biotechnology research? What will be the position of these transnational agribusiness towards this enormous section of humanity that still live largely outside the commercial market economy? This issue goes far beyond economics; it is also a matter for deep ethical consideration. Fundamentally, the question is do small-scale farmers of the developing world also have a right to share in the benefits of biotechnology? If the answer is yes, then what is the role of international and national governments to ensure that this right is met? I believe we must give this matter serious thought.

STANDING UP TO THE ANTISCIENCE 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 ask myself how it is that so many people believe to the contrary? First, there seems to be a growing fear of science, per se, as the pace of technological change increases. The late British physicist and philosopher-writer C.P. Snow first wrote about the split between scientists and humanists in his little book, ***The Two Cultures***, published in 1962. It wasn't that the two groups necessarily disliked each other, rather they just didn't know how to talk to each other. The rift has continued to grow since then. 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***—which reported that poisons were everywhere, killing the birds first and then us—struck a very sensitive nerve. Of course, this perception was not totally unfounded. As pointed out in Bittman's little book, ***The Good Old Days: They Were Terrible,*** about environmental quality in America (and the United Kingdom and other industrialized nations), in the late 19th and early 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 improve air and water quality, protect wildlife, control the disposal of toxic wastes, protect the soils, and reduce the loss of biodiversity. In almost every environmental category far more progress is being made than most commentators in the media are willing to admit. Why? I believe that it's because apocalypse sells. Sadly, all too many scientists, many of whom 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 Rifkin's anti-biotechnology crowd, what are we to think? When scientists lend their names and credibility 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, charlatan scientists like T.D. Lysenko, whose pseudo-science in agriculture and vicious persecution of anyone who disagreed with him, contributed greatly to the collapse of the former USSR.

Recently a science writer named Gregg Easterbrook wrote an article about me in the U.S. magazine, ***Atlantic Monthly***. While I have never met him, I was intrigued by the brief biographical sketch provided about him, which labeled him an eco-realist. I was prompted to buy his new book, ***A Moment on the Earth***, published by Penguin in 1996, which I am now reading. It's a fascinating and provocative book, based upon a massive amount of research. Calling himself an "eco-realist" Easterbrook's central appeal is that the worthy inclinations of environmentalism must become grounded in rationality. "Logic, not sentiment," he contends, "best serves the interests of nature." Easterbrook provides much documentation that in the Western world, "the Age of Pollution is nearly over" asserting that "aside from weapons, technology is not growing more dangerous and wasteful but cleaner and more resource-efficient."

However, Easterbrook correctly points out that as positive as trends are in the First World, they are negative in the Third World, where environmental degradation is occurring at an alarming rate, with poverty and rapid population growth the underlying causes. While it is certainly technically feasible for plant Earth to support a human population several times larger than at present without ecological harm, the point is that our current social, political, and economic systems cannot support rapidly growing populations at an adequate standard of living. Thus short-term global population stabilization is of paramount importance.

In sharp contrast to the rich countries, where most environmental problems have been urban, industrial, and a consequence of high incomes, the critical environmental problems in most of the low-income developing countries remain rural, agricultural, and poverty-based. More than one-half of the world's very poor live on lands that are environmentally fragile, and they rely on natural resources over which they have little legal control. Land-hungry farmers resort to cultivating unsuitable areas, such as erosion-prone hillsides, semiarid areas where soil degradation is rapid, and tropical forests, where crop yields on cleared fields drop sharply after just a few years.

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 impacts of science-based technology on the land. Had 1961 yields still prevailed today, three times more land in India would be needed to equal 1992 cereal production. Obviously, such a surplus of land of the same quality is not available, and especially not in populous China and India.

I have calculated that if the USA attempted to produce the 1990 harvest of the 17 most important crops with the technology and yields that prevailed in 1940 it would have required an additional 188 million hectares of land of similar quantity. This theoretically could have been achieved either by plowing up 73% of the nation's permanent pastures and range lands, or by converting 61% of the forest and woodland area to cropland. In actuality, since many of these lands are of much lower productive potential than the land now in crops, it really would have been necessary to convert an even larger portion of the range lands or forests and woodlands to crop production. Had this been done, imagine the additional havoc from wind and water erosion, the obliteration of forests, extinction of wildlife habitats, and the enormous reduction of outdoor recreational opportunities.

In his writings, Professor Robert Paarlberg, who teaches at Wellesley College and Harvard University in the USA, has sounded the alarm about the consequences of the debilitating debate between agriculturalists and environmentalists about what constitutes so-called sustainable agriculture in the Third World. This debate has confused—if not paralyzed—policy makers in the international donor community who, afraid of antagonizing powerful environmental lobbying groups, have turned away from supporting science-based agricultural modernization projects, so urgently needed in sub-Saharan Africa and parts of Latin America and Asia. The result has been increasing misery in smallholder agriculture and accelerating environmental degradation.

This policy deadlock must be broken. In doing so, we cannot lose sight of the enormous job before us to feed 10 billion people, most of whom will be born into abject poverty in low-income, food-deficit nations. And we must also recognize the vastly different circumstances faced by farmers in different parts of the Third World, and assume different policy postures. For example, in Europe or the U.S. Corn Belt, the application of 300 to 400 kg of fertilizer nutrients per hectare of arable land can cause some environmental problems. But surely, increasing fertilizer use on food crops in sub-Saharan Africa from around 5 kg of nutrients per hectare of arable land to 30 to 40 kg is not an environmental problem but rather a central component in Africa's environmental solution.

CLOSING COMMENTS

Twenty-seven 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. Extremists in the environmental movement from the rich nations seem to be trying to stop scientific progress in its tracks. Small, vociferous, well-funded, and highly effective anti-science and technology groups are slowing the application of new technology, whether it be developed from biotechnology or more conventional scientific methods.

I am particularly alarmed by those who seek to deny small-scale farmers of the Third World—and especially those in sub-Saharan Africa—access to the improved seeds, fertilizers, and crop protection chemicals that have allowed the affluent nations the luxury of plentiful and inexpensive foodstuffs which, in turn, has accelerated their economic development. While consumers in the affluent nations can certainly afford to pay more for the so-called organically produced foods, the one billion chronically undernourished people of the low-income, food-deficit nations cannot. As Richard Leakey likes to remind his environmental supporters, "you have to have at least one square meal a day to be conservationist or environmentalist".

At the closure of the Earth Summit in 1992 at Rio de Janeiro, 425 members of the scientific and intellectual community presented to the Heads of State and Government what is now being called the Heidelberg Appeal. Since then, some 3000 scientists have signed this document, including myself. Permit me to quote the last paragraph of the Appeal:

> "The greatest evils which stalk our Earth are ignorance and oppression, and not science, technology, and industry, whose instruments, when adequately managed, are indispensable tools of a future shaped by Humanity, by itself and for itself, in overcoming major problems like overpopulation, starvation, and worldwide diseases."

Agricultural scientists, agribusiness leaders, and policy makers 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. Let us all remember that world peace will not be built on empty stomachs and human misery. Deny the small-scale, resource-poor farmers of the developing world access to modern factors of production—such as improved varieties, fertilizers and crop protection chemicals—and the world will be doomed, not from poisoning, as some say, but from starvation and social and political chaos.