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Feeding a world of 10 billion people: the miracle ahead

Norman E. Borlaug
The Sasakawa Africa Association, c/o CIMMYT, Apdo 6-641, Mexico DF, CP 06600

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The invention of agriculture — some 10,000–12,000 years ago — heralded the dawn of civilization. It began with rain-fed, hand-hoe agriculture, which evolved into 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 behoves us to remember that this axiom still remains valid today.

I am now in my 53rd year of continuous involvement in food production programmes in developing nations. During this period, I have seen much progress in increasing the yields 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 more than tripling the world food supply during the past three decades, the so-called "Green Revolution" in cereal production has not solved the problem of chronic undernutrition for hundreds of millions of poverty-stricken people around the world. They are unable, due to unemployment or under-employment, to purchase the food they need, despite its abundance in world markets.

To give you some idea of the rate of population explosion we are now experiencing, in 1914, when I was born, there were only about 1.6 billion mouths to feed; today, we number some 5.8 billion.

The complexities and challenges of feeding a world of 10 billion people will almost certainly occur during the lifetime of most students present here tonight.

Poets — and city folk — love to romanticize agriculture, portraying it as some sort of idyllic state of harmony between humankind and nature. How far this is from the truth! Since Neolithic man — or most probably woman — domesticated the major crop and animal species some 10 to 12 millennia ago, agriculture has been a struggle between the forces of natural biodiversity and the need to produce food under increasingly intensive production systems. Thanks to advances in science during this

century — which is when the population bomb really went off — food production has kept ahead of population growth and, in general, has become more reliable. But, with the global population currently increasing by one billion each decade, meeting future food demand is becoming ever-more challenging and worrisome.

Our world food supply

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. Of this total, 99% was produced on the land — only about 1% came from the oceans and inland waters, even though 70% of the earth's surface is covered with water. Plant products constituted 93% 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 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 an adequate diet (2,350 calories, principally from grain) in 1994 for 6.4 billion people — about 800 million more than the actual population. However, had people in Third World countries attempted to obtain 30% of their calories from animal products — as in the US, Canada, or EEC countries — a world population of only 2.6 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. *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 and about 8.3 billion by 2025, before *hopefully* stabilizing at about 11 billion toward the end of the 21st century.

Raising yield levels on existing agricultural lands

While somewhat of an oversimplifying assumption, since 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. To meet the projected food demands, therefore, the average yield of all cereals must be increased by 80% between 1990 and the year 2025. 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.

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. 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 plough.

What can we expect from biotechnology?

Over 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 semi-dwarf wheat and rice varieties being grown commercially, 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 to higher levels, if we are to cope with the food production challenges before us. One possible breakthrough may be the New Plant Type rice developed by the International Rice Research Institute and now being improved for grain filling, with research support, using genetic engineering techniques, from the Borlaug Institute at De Montfort University.

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 fibre 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 and 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 herbicide use by much more specific dosages and interventions.

The development of transgenic plants for the potential control of viral and fungal diseases is not nearly as far developed. Nevertheless, there are some very promising examples of specific virus coat protein genes in transgenic varieties of potatoes and rice that confer considerable protection. Different promising disease-resistant genes 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 sorts 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 grains 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?

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.

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. For the Third World, 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, including Professor Elliott of this university, anticipate great benefits from biotechnology in meeting our future food and fibre 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 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 trans-national agribusinesses towards this enormous section of humanity that still lives largely outside the commercial market economy? This issue goes far beyond economics; it is also a matter for deep ethical consideration. Fundamentally, the issue is whether 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 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 is not so, I ask myself how it is that so many people believe 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*, which was published in 1962. It was not that the two groups necessarily disliked each other, rather that 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 prospect 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 Bittman's little book (*The Good Old Days: They Were Terrible*) about environmental quality in America (and in the United Kingdom and other industrialized nations) in the late 19th and early 20th century, graphically pointed out, we were poisoning ourselves. 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 the 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 is 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 US 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 is a fascinating and provocative book, based upon a massive amount of research. Following are some of his conclusions, and I quote:

1) If the worthy inclinations of environmentalism are to be transformed from an ephemeral late-twentieth-century political fashion to a lasting component of human thought, the ecological impulse must become grounded in rationality. Logic, not sentiment, best serves the interests of nature.
2) In the Western world the Age of Pollution is nearly over. Almost all of the pollution issues will be solved within the lifetimes of [this audience]. Aside from weapons, technology is not growing more dangerous and wasteful but cleaner and more resource-efficient. Clean technology will be the successor to high technology.
3) As positive as trends are in the First World, they are negative in the Third. One reason why the West must shake off its instant-doomsday thinking about the United States and Western Europe is so that resources can be diverted to ecological protection in the developing world.
4) People may not sit above animals and plants in any metaphysical sense, but clearly are superior in their place in the natural order. Either humanity was created by a higher power, or humanity rose to its position through purely natural processes; in [either] case it is absurd for environmental dogma to consider the human role in nature to be bad.
5) In principle, the human population is no enemy of nature. Someday human population may be many times larger than at present, without ecological harm. But the world of the present has more people than current social institutions and technological knowledge can support at an adequate material standard. Thus short-term global population stabilization is desperately required.
6) Nature is not ending, nor is human damage to the environment "unprecedented." Nature has repelled forces of a magnitude many times greater than the worst human malfeasance. Nature still rules much more of the Earth than does genus *Homo*. To people the distinction between artificial and natural means a great deal. To nature, it means almost nothing at all.
7) The fundamental force of nature is not a moral struggle between hunter and hunted.

Most living things center their existence on cooperation and coexistence, the sort of behavior women and men should emulate.

8) Nature, limited by spontaneous interactions among elements randomly disturbed, may have an upper-bound limit on its potential to foster life and evolve. Yet nature appears to enjoy fostering life and evolving. So perhaps nature hopes to acquire new sets of abilities, such as action by design. Therefore maybe *nature needs us*.

Certainly, we must be environmentally responsible in our efforts to produce ever-greater quantities of food to feed our unrelenting population. But we must also face up to the fact that we cannot turn back the clock and use technologies that were adequate for a much smaller world population.

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 half of the world's very poor live on lands that are environmentally fragile and rely on natural resources over which they have little legal control. Land-hungry farmers resort to cultivating unsuitable areas, such as erosion-prone hillsides, semi-arid 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 impact of science-based technology on the land. Had 1961 yields still prevailed today, three times more land in China and the United States and two 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 United States 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 rangelands, 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 under crops, it really would have been necessary to convert an even larger portion of the rangelands or forests and woodlands to crop production. Had this been done, imagine the additional havoc from wind and water erosion, the obliteration of forests, and 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 United States, 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 — policymakers in the international donor community who, afraid of antagonizing powerful environmental lobbying groups, have turned away from supporting science-based agricultural modernization projects which

are 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 US corn belt, the application of 300–400 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 30–40 kg is not an environmental problem but rather a central component of 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 to 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 doing everything they can to stop scientific progress in its tracks. Small, but vociferous and highly effective and well-funded, anti-science and technology groups are slowing the application of new technology, whether it be developed from biotechnology or more conventional methods of agricultural science. 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 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. As Richard Leakey likes to remind his environmental supporters, "you have to have at least one square meal a day to be a conservationist or an 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 3,000 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 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. 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.