Feeding a World of 10 Billion People

The TVA/IFDC Legacy

An International Center for Soil Fertility and Agricultural Development

FEEDING A WORLD OF 10 BILLION PEOPLE: The TVA/IFDC Legacy

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IFDC—An International Center for
Soil Fertility and Agricultural Development
Travis P. Hignett Memorial Lecture
March 14, 2003
Muscle Shoals, Alabama (U.S.A.)

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Library of Congress Cataloging-in-Publication Data

Borlaug, N. E.
Feeding a world of 10 billion people : the TVA/IFDC legacy / prepared by Norman E. Borlaug.
p. cm.
Third lecture, 1st published, in the Travis P. Hignett Memorial Lecture series.
Includes bibliographical references (p.).
ISBN 0-88090-144-6
1. International Center for Soil Fertility and Agricultural Development--History. 2. Fertilizers--History. 3. Soil fertility--History. 4. Agricultural innovations--History. 5. Food supply--History. I. Title.
S633.B67 2003
631.8--dc22
2003021857

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IFDC publications are listed in *IFDC Publications*, General Publication IFDC–G-1; the publications catalog is free of charge.

Third Travis P. Hignett Memorial Lecture

The Travis P. Hignett Memorial Lecture Series was initiated during 1994 by IFDC to honor a distinguished chemist, chemical technologist and developer, author, and administrator. Mr. Hignett (1907-89) received global recognition for his many accomplishments in the fertilizer world over a period of some 50 years. After a 35-year career with the Tennessee Valley Authority, Hignett served as a special consultant at IFDC for more than a decade. Often referred to as the "Father of Fertilizer Technology," Hignett held 15 patents and was the author of approximately 150 publications. He received a number of awards, including the Francis New Memorial Medal from the Fertiliser Society of London in 1969. This lecture series is being sponsored by the Hignett Memorial Fund, which was established in 1987 to honor Mr. Hignett.

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FEEDING A WORLD OF 10 BILLION PEOPLE: The TVA/IFDC Legacy[1]

Norman E. Borlaug[2]

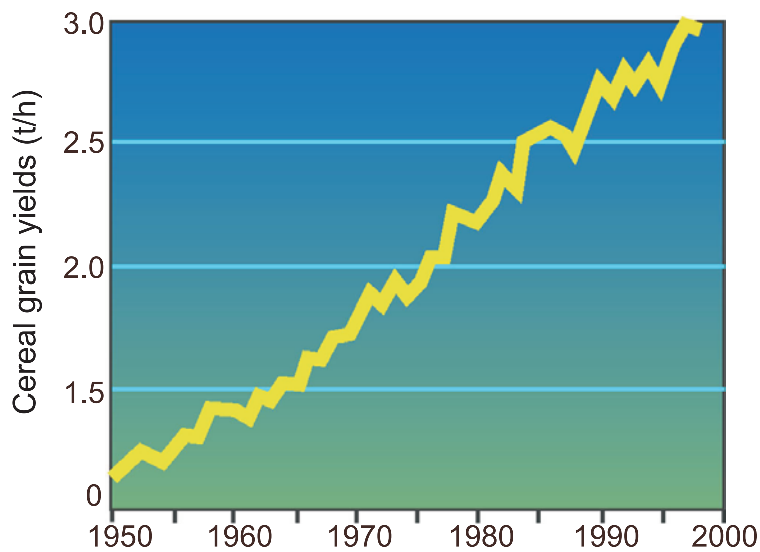
Introduction

It is an honor to be invited to give the Travis P. Hignett Memorial Lecture, a distinguished chemist, chemical technologist and developer, author, and administrator, who spent 35 years working for the Tennessee Valley Authority (TVA) and another 10 years as a special consultant at the International Fertilizer Development Center (IFDC). Although I never had the pleasure of knowing him personally, I understand that he was revered at TVA and IFDC and was often referred to as the "Father of Fertilizer Technology," holding 15 patents in his own right.

My purpose here today is to highlight the role that science and technology, especially fertilizer, has played in improving the quantity, quality, and availability of food for the world's people over the past 50 years and to explore the challenges we face to feed a world of 10 billion people, which are likely to exist on the planet Earth by the end of this new century

I am now in my 59th year of continuous involvement in agricultural research and production in the low-income, food-deficit developing countries. Over these nearly six decades I have worked with many colleagues, political leaders, and farmers to transform food production systems in the developing world. During the past 40 years, thanks to a continuing stream of high-yielding varieties that have been combined with improved crop management practices, food production has more than kept pace with global population growth.

Globally, cereal grain yields have tripled over the past 40 years (Figure 1). This has resulted in per capita world cereal supplies that are 23% higher today and real prices that are 65% lower than in 1961 (FAO, 2002). Much of these gains have been made possible by the adoption of productivity-enhancing technology, such as chemical fertilizer (Figure 2). Despite the tremendous expansion in food production, two billion people still lack reliable access to safe, nutritious food, and 800 million of them—including 150 million children—are chronically malnourished. Thus, there is no room for complacency on the food production and poverty-alleviation fronts.



Source: FAOSTAT, 1999.

Figure 1. Average Global Cereal Yield

[1]Travis P. Hignett Memorial Lecture, IFDC, March 14, 2003, Muscle Shoals, Alabama.

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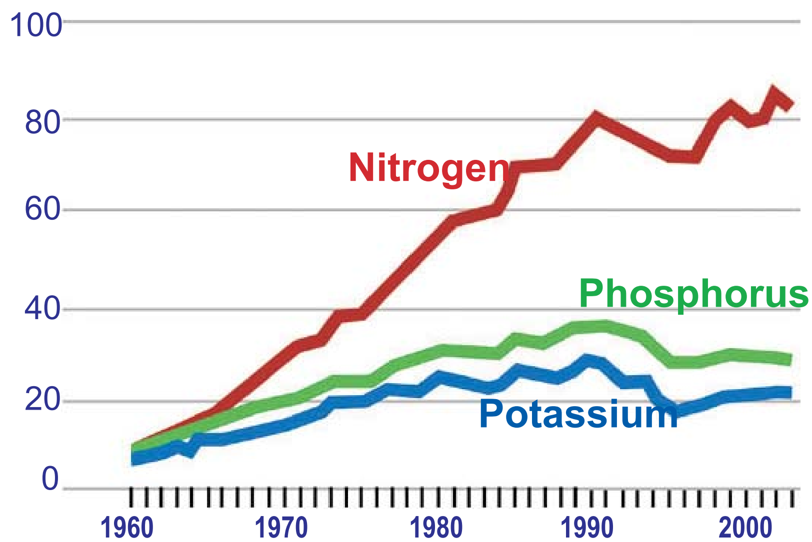


Source: FAO.

Figure 2. World Fertilizer Consumption (million tons nutrient)

At that time, phosphorus was the most limiting nutrient for agricultural production in the Tennessee Valley. Because of this situation, TVA began to produce superphosphate and made available free to farmers who agreed to participate in a farm demonstration program to illustrate the benefits of P use on their crops. This became known as the TVA Test-Demonstration program; during the postwar era this program had spread to more than 15,000 demonstration farms in 35 states across the country. During the agency's first decade, agricultural production levels tripled on these demonstration farms.

Before addressing the topic of this paper, first I would like to review briefly the fascinating story of the TVA agricultural resource development program and trace how TVA's work—and later that of IFDC—came to benefit the world, especially with respect to fertilizer science and technology.

TVA's Agricultural Resource Development Program

TVA's fertilizer science roots can be traced to 1918 when the Wilson Dam and the nitrate plant complex were constructed to produce explosives for World War I. The war ended before the nitrate production complex was finished, and the facilities lay idle for several years, while controversy swirled around whether they should be sold or used for the public good. When President Franklin D. Roosevelt signed the TVA Act in 1933, the controversy was settled and the Muscle Shoals facilities were turned over to the new agency. In 1933 most Tennessee Valley farmers were using outdated agricultural practices. Seven out of 12 million cleared acres needed soil-erosion control measures, and 1 million acres were eroded to the point of abandonment. Much of the land required phosphate and lime to produce successful cover crops that would control erosion. TVA introduced fertilizers and new farming systems that would save the soil and increase farm income.

During World War II, TVA's Muscle Shoals facilities were given a munitions production mandate again. During the war years, TVA supplied 60,000 tons of phosphorus and 103,000 tons of ammonium nitrate required by the U.S. Armed Forces. These chemicals were used in bombs, shells, tracer bullets and other munitions. The Muscle Shoals facilities also produced calcium carbide for use in producing synthetic rubber and dicalcium phosphate for use as an animal feed supplement.

After WWII ended, TVA forged ahead with the development of new and improved fertilizer products and process technologies to manufacture new high-analysis fertilizers, which helped American farmers to begin making significant advances in crop yields. Commercial sales of fertilizer in the Valley increased at a rate three times faster than in the rest of the country. And the results were evident; acre for acre, farm productivity in the Valley reached levels never seen before. Forty years after the fertilizer program was started, the farms of the once-ruined Tennessee Valley were twice as productive per acre as the average American farm.

Some of the fertilizer products that TVA developed include triple superphosphate (TSP), calcium metaphosphate, and diammonium phosphate (DAP). DAP, which became very popular with the fertilizer industry, was quickly recognized as a product with tremendous potential. TVA also pioneered the concepts and procedures necessary for the rapid and successful growth of bulk blending—an important segment of the fertilizer industry. Bulk blending is the physical blending of granular fertilizer materials to yield desired amounts of plant nutrients. TVA was also a leader in nitrogen fertilization, working on slow-release fertilizer products and developing systems for direct injection of ammonia into soils and through irrigation.

The Korean Conflict once again reactivated TVA's military role in producing strategic chemicals for the U.S. Armed Forces. At the same time, the agricultural mission continued to grow as farmers sought to increase agricultural production through higher crop yields.

TVA's great strides in fertilizer science were paying off in the United States and gained attention around the world. In 1960, the name TVA National Fertilizer Development Center (NFDC) was formally adopted. NFDC scientists and engineers are responsible for developing the technology for over 75% of the fertilizer products used today. Patents on TVA technology exceed 300 and over 700 licenses have been granted for use of this technology.

Creation of IFDC

The beginnings of IFDC were strongly influenced by experiences of NFDC, which by 1960 had become the acknowledged world center of excellence in fertilizer technology, and especially for the development of new or improved products and processes.

NFDC's charter called for it to engage in work that would benefit the farmers and people of the United States. It was also allowed to undertake projects requested and financed by other U.S. government agencies. Between 1960 and the mid-1970s, at the request of USAID and the U.S. State Department, TVA experts provided technical assistance to more than 60 countries. The requests for help swelled with the alarming food and fertilizer shortages that began in 1973. These fertilizer shortages were generally thought to be caused by an Arab oil embargo although neglect of agriculture by some developing country governments was also a factor.

In April 1974, Henry Kissinger, U.S. Secretary of State, proposed to the United Nations General Assembly the establishment of an international effort, supported by the United States, to improve fertilizer production and use in the developing world. The idea met with ready acceptance. In view of NFDC's critical mass of fertilizer development specialists and the excellent facilities available at Muscle Shoals, it was decided to establish a new International Fertilizer Development Center (IFDC) on TVA land adjacent to NFDC. In October 1974, IFDC was established as a private, nonprofit corporation under Alabama law (later designated as a nonprofit public international organization). Dr. Donald L. McCune, then Director of the NFDC international staff, was appointed as IFDC's first Managing Director. I have had the pleasure of serving on the IFDC Board of Directors these past 9 years and of seeing its current President and CEO, Dr. Amit Roy, grow in his leadership of the Center.

Today IFDC is the world's only nonprofit, science-based organization with the mandate to address the integrated soil nutrient management needs associated with moving toward a sustainable global food system. Because it is composed of an international, multidisciplinary, multilingual staff, IFDC can provide an unbiased opinion regarding most facets of fertilizer sector development. The IFDC staff, recruited from more than 20 countries, is both internationally and technically diverse with almost one-half of the total being chemical engineers, chemists, economists, agronomists, geologists, soil scientists, marketing specialists, and sociologists. IFDC is able to conduct unique research and development programs and projects because of three complementary factors: (1) the multidisciplinary structure of its task teams used for project planning and implementation; (2) the ability to produce and test experimental fertilizers in laboratories, pilot plants, greenhouses, and experiment stations and fields in the developing countries; and (3) linkages with research and development institutions around the world.

IFDC has pioneering research in nitrogen-use efficiency and in the use of phosphate rock for direct application. Pathways of nitrogen loss were studied intensively, in collaboration with IRRI scientists. IFDC geologists and soil chemists have characterized dozens of phosphate deposits and developed data on their potential use in fertilizers. IFDC engineers and fertilizer technologists have improved production processes.

Since its inception in 1974, the Center has conducted technology transfer activities in more than 130 countries. IFDC has contributed to the development of human resources and institutional capacity-building in 150 countries through more than 640 international training programs for over 8,400 participants (IFDC, 2003ab). In addition to the international programs and study tours, IFDC conducts most of its training as part of its long-term agricultural development projects overseas; this training annually involves more than 8,000 agro-input dealers, trade association members, progressive farmers, and others in hundreds of relevant technical, business, marketing, and management programs.

IFDC has demonstrated success in establishing effective private-sector agricultural input and output marketing systems, trade associations, small and medium enterprises, and technology transfer in Albania, Bangladesh, and Kosovo. By using a holistic approach IFDC is assisting the entrepreneurs in establishing market economies to trigger economic development in their respective countries.

For the past few years, IFDC has been introducing a modified form of urea fertilizer in Bangladesh, Nepal, and Vietnam that improves the standard of living of rice-growing farmers and reduces the environmental impact of fertilizer use. In the new process, urea is turned into small briquettes—urea supergranules—that are applied well below the soil surface near the plants' roots. The use efficiency of the fertilizer is greatly improved because the nitrogen is trapped where it is needed. Nitrogen gases lost to the atmosphere are also reduced. Since less fertilizer is required and more food is produced, this practice has made a substantial contribution to poverty alleviation and environmental protection.

In the late-1990s IFDC developed a package of inputs and practices, called ISFM, which raises the agricultural productivity level while maintaining the natural resource base. The package includes the combined use of soil amendments, organic materials, and mineral fertilizers to replenish the soil nutrients and improve the efficiency and cost-effectiveness of external inputs. The technology package produces yields that are 2-3 times higher than average yields. Emphasis is placed on participatory approaches to develop ISFM options suitable to agro-ecological and socioeconomic conditions of farmers considering their needs, interests, and capacities. Thus, farmers select, experiment, and adapt in their own fields the methods developed with research and extension staff. This freedom of choice and action allows for innovation.

Agriculture and Population

In geologic terms, the domestication of plant and animal species is a recent event. Archaeological evidence indicates that all the primary cereals, economically important legumes, root crops, and animal species that are our principal sources of food were domesticated some 10,000 to 12,000 years ago. The process may well have begun when Neolithic women, faced with food shortages when their menfolk failed to bring home enough food from hunting forays, decided that something had to be done and began searching for a means to ensure a more permanent and reliable supply. This was achieved by sowing seed of the same wild grain species they had been collecting for untold millennia to supplement their meat diet. Thus, agriculture was born, and with it, permanent human settlements and the beginning of civilization. With the development of agriculture, the condition of humankind began to improve markedly, and human numbers, estimated to have been 15 million at that time, began to increase at an accelerated rate. A more stable food supply resulted in better nutrition and the development of a settled way of life, leading to higher survival rates and yet more rapid population growth.

World population presumably doubled four times—to about 250 million—from the beginning of agriculture to the start of the Christian era. It doubled again, to 500 million, by about 1650. The next doubling of the population required only 200 years, producing a population of one billion by 1850. At about that time the discovery of the nature and cause of infectious diseases—the dawn of modern medicine—began to lower death rates. It took only 80 years for the next doubling—to two billion people—which occurred about 1930. Shortly thereafter, the development of sulfa drugs, antibiotics, and improved vaccines led to a further substantial reduction in death rates, especially among infants and children. The next doubling of population took only 45 years—to about 1975, when global population reached four billion. The next doubling is projected by 2020, again only 45 years, representing a 533-fold increase since the discovery of agriculture.

While growth of world population overall is now slowing, the current rate in much of the developing world is still frighteningly high. Over the next 50 years, world population is likely to swell to 9-10 billion people, with 90% being born in low-income developing countries, and very likely into conditions of poverty. Hopefully, the UN predicts that by the end of the 21st century, world population will stabilize at 10-11 billion people, and much of the poverty that still haunts the world will have been abated. I must confess that I am less optimistic than many about how fast world population will slow, given the persistence of pverty and illiteracy.

There are two aspects to the problem of feeding the world's people. The first is the complex task of producing sufficient quantities of the desired foods to satisfy people's needs. The second task, equally or even more complex, is to distribute the food equitably. The chief impediment to equitable food distribution is poverty—lack of purchasing power. About 42% (2.6 billion) of the world's people are farmers and rely largely on their own agricultural efforts to feed themselves. Millions of these rural poor remain food insecure. Thus, only by increasing agricultural productivity in food-deficit areas can both aspects of the world food problem be ameliorated.

Food Production and the Role of Science

In 2000, global food production of all types stood at 5.2 billion tons, representing some 2.7 billion tons of edible dry matter (Table 1). Of this total, 98% was produced on the land; only 2% came from the oceans and the inland waters (aquaculture is likely to increase fish production substantially in years ahead). Plant products constitute 92% of the human diet, with about 30 crop species providing most of the world's calories and protein. These included eight species of cereals, which collectively accounted for 70% of the world food supply (and 60% of direct human food use). Animal products, constituting 7% of the world's diets, come indirectly from plants. A third source of food, microbial fermentation is used

Table 1. World Food Supply, 2000

Commodity	Production		
	Gross Tonnage	Edible Matter[a]	Dry Protein[a]
	(million tons)		
Cereals	**2,064**	**1,718**	**171**
Maize	593	524	54
Wheat	585	516	61
Rice	601	407	34
Barley	135	118	12
Sorghum/millet	84	76	7
Roots & Tubers	**698**	**186**	**12**
Potato	328	71	8
Sweet potato	139	42	2
Cassava	177	66	1
Legumes, oilseeds/nuts	**165**	**112**	**39**
Sugarcane & sugar beet[b]	**150**	**150**	**0**
Vegetables & melons	**692**	**81**	**7**
Fruits	**466**	**64**	**3**
Animal products	**992**	**196**	**87**
Milk, meat, eggs	866	164	66
Fish	126	32	23
All Food	**5,227**	**2,507**	**319**

a. At zero moisture content, excluding inedible hulls and shells.
b. Sugar content only.

Source: FAOSTAT, July 2002.

primarily to produce certain vitamins and amino acids. These products are important nutritionally, but the quantities are relatively small and they are not included in the survey.

Until the 19th century, crop improvement was in the hands of farmers, and food production grew largely by expanding the cultivated land area. Improvements in farm machinery expanded the area that could be cultivated by one family, especially in the United States. Machinery made possible better seedbed preparation, moisture utilization, and improved planting practices and weed control, resulting in modest increases in yield per hectare.

Although forgotten by 1900, the potato famine (late wilt, *phytoptora* spp.) that had swept across northern Europe in 1845-51 and resulted in the starvation of several million people, led to the subsequent migration of millions of Europeans to the Americas during 1850-60 (Daly, 1996). This restored a reasonable, yet still tenuous balance in the land-food-population equation. Moreover, the population pressures and declining soil fertility—due to increasing agricultural intensification—stimulated European scientists to develop the first theoretical foundations in soil chemistry and crop agronomy for soil fertility recapitalization.

By the early-1800s, German scientist Justus von Leibig and French scientist Jean-Baptiste Boussingault had established important theoretical foundations in soil chemistry and crop agronomy. Sir John Bennett Lawes produced superphosphate in England in 1842, and shipments of Chilean nitrates (nitrogen) began arriving in quantities to European and North American ports in the 1840s. However, the use of organic fertilizers (animal manure, crop residues, green manure crops) remained dominant into the early 1900s. Of course, the most skillful and dedicated users of organic fertilizers (which also included human waste) were the Chinese, Japanese, and Koreans.

The groundwork for more sophisticated genetic improvement of crop plant species was laid by Charles Darwin, in his writings on the variation of life species (published in 1859), and by Gregor Mendel through his discovery of the laws of genetic inheritance (reported in 1865). Darwin's book immediately generated a great deal of interest, discussion and controversy. Mendel's work was largely ignored for 35 years. The rediscovery of Mendel's work in 1900 provoked tremendous scientific interest and research in plant genetics.

The first decade of the 20th century brought a fundamental scientific breakthrough that was followed by the rapid commercialization of the breakthrough. In 1909, Fritz Haber, Nobel Laureate in Chemistry (1918), demonstrated the synthesis of ammonia from its elements. Four years later—in 1913—the company BASF, thanks to the innovative solutions of Karl Bosch, began operation of the world's first ammonia plant. The expansion of the fertilizer industry was soon arrested by WWI (ammonia used to produce nitrate for explosives), then by the great economic depression of the 1930s, and then again by the demand for explosives during WWII. However, after the war, rapidly increasing amounts of nitrogen became available and contributed greatly to boosting crop yields and production.

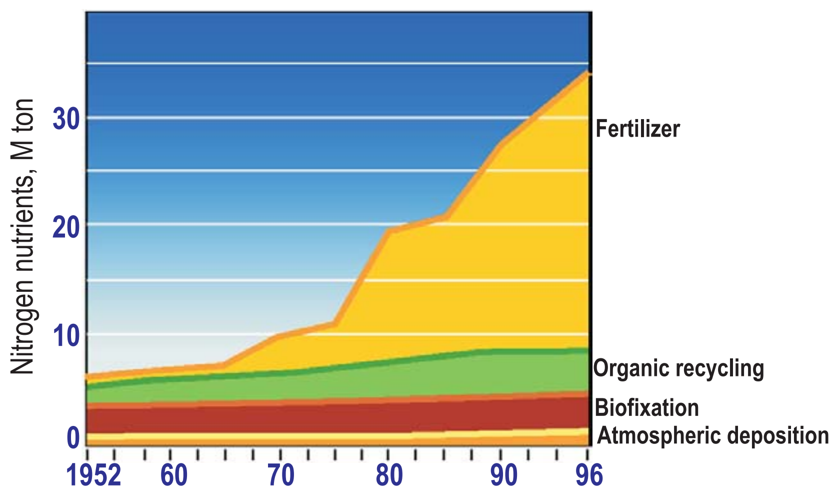
By the 1930s, much of the scientific knowledge needed for high-yielding agricultural production was available in the United States. However, widespread adoption was delayed by the great economic depression of the 1930s, which paralyzed the world's agricultural economy. It was not until WWII brought a much greater demand for food supplies that the new research findings began to be applied widely (excluding nitrogen fertilizer), first in the United States and later in many other countries.

It is only since WWII that inorganic fertilizer use, and especially the application of low-cost nitrogen derived from synthetic ammonia, has become an indispensable component of modern agricultural production (nearly 80 million nutrient tons of nitrogen are now consumed annually). As mentioned previously, TVA and IFDC have played key roles in the science and development of fertilizer production and use efficiency, both in agriculture and plantation forestry.

Hybrid U.S. corn (maize) cultivation led the modernization process. In 1940, U.S. farmers produced 56 million tons of maize on roughly 31 million ha

(77 million acres), with an average yield of 1.8 tons/ha. In 2000, U.S. farmers produced 252 million tons of maize on roughly 29 million ha, with an average yield of 8.6 tons/ha.

Professor Vaclav Smil of the University of Manitoba, who has studied nitrogen cycles for most of his professional life, estimates that 40% of the world's 6 billion people are alive today thanks to the Haber-Bosch process, which produces 80 million tons per year of chemical nitrogen (Smil, 1999). It would be impossible for organic sources to replace this amount of nitrogen. In fact, Smil calculates that organic sources of nitrogen could only feed 4 billion of the world's people, not the 6.2 billion we currently have. This message on the importance of chemical nitrogen was not lost on China, the world's greatest organic recycler, which beginning in the late 1970s relied increasingly on chemical fertilizer to raise yields and rapidly expand its food production (Figure 3).



Source: FAO.

Figure 3. Nitrogen Inputs Into China's Agriculture, 1952-96

The Green Revolution

Over the past four decades, sweeping changes have occurred in the factors of production used by farmers in many parts of the developing world but nowhere more dramatic than in India, Pakistan, China and other developing countries of Asia (Table 2). High-yielding semi-dwarf varieties are now used on 84% and 74% of the wheat and rice area, respectively; irrigation has more than doubled—to 175 million ha; fertilizer consumption has increased more than 30-fold and now stands at about 70 million tons of total nutrients; tractor use has increased from 200,000 to 4.8 million units; and cereal production has tripled—from 309 to 962 million tons.

In describing the rapid spread of the new wheat and rice technology across Asia, William Gaud, the USAID Administrator, in a talk given on March 8, 1968, to the

Table 2. Changes in Factors of Production in Developing Asia

	Adoption of Modern Varieties		Irrigation	Fertilizer Nutrient Consumption	Tractors	Cereal Production
	Wheat	Rice				
	(M ha/% area)		(million ha)	(million tons)	(million)	(million tons)
1961	0 / 0%	0 / 0%	87	2	0.2	309
1970	14 / 20%	15 / 20%	106	10	0.5	463
1980	39 / 49%	55 / 43%	129	29	2.0	618
1990	60 / 70%	85 / 65%	158	54	3.4	858
2000	70 / 84%	100 / 74%	175	70	4.8	962

Source: FAOSTAT, July 2002; author's estimates of modern variety adoption based on CIMMYT and IRRI data.

Society for International Development in Washington D.C., said:

> *These and other developments in the field of agriculture contain the makings of a new revolution. It is not a violent Red Revolution like that of the Soviets or the White Revolution in Iran. But rather, I call it a Green Revolution.*

Thus, the term "Green Revolution" was coined. To me, it symbolizes the process of applying agricultural science to develop modern techniques for Third World food production conditions. I believe that there has tended to be too much focus on the wheat and rice varieties themselves, as if they alone can produce miraculous results. Certainly, modern varieties can shift yield curves higher due to more efficient plant architecture and the incorporation of genetic sources of disease and insect resistance. However, modern, disease-resistant varieties can only achieve their genetic yield potential if systematic changes are also made in crop management, such as in dates and rates of planting, fertilization, water management, and weed and pest control. Moreover, many of these crop management changes must be applied simultaneously if the genetic yield potential of modern varieties is to be fully realized. For example, higher soil fertility and greater moisture availability for growing food crops also improve the ecology for weed, pest, and disease development. Thus, complementary improvements in weed, disease, and insect control are also required to achieve maximum benefits.

The Green Revolution has been a much-debated subject. During the late 1960s, the initial euphoria over the high-yielding wheat and rice varieties—and more intensive crop production practices—was followed by a wave of criticism. Some criticism reflected a sincere concern about social and economic problems in rural areas that were not—and cannot—be solved by technology alone. Some criticism was based on premature analyses of what was actually happening in areas where the Green Revolution technologies were being adopted. Some criticism focuses on issues of environmental damage and sustainability. Many of these criticisms have some element of truth to them. Obviously, wealth has increased in irrigated areas, relative to less-favored rainfed regions, thus increasing income disparities. Cereals, with their higher yield potential, have displaced pulses and other lower yielding crops, but with a net gain in total calories produced. Farm mechanization has displaced low-paid laborers, although many have found better-paying jobs off the farm in towns and cities. High-yielding cereal varieties have replaced lower yielding land races, generally with significant improvements in disease resistance, especially in the case of wheat (Borlaug, 2000).

For those whose main concern is protecting the "environment," what would the world have been like without the technological advances that have occurred? Had the global cereal yields of 1950 still prevailed in 1999 we would have needed nearly 1.2 billion ha of additional land of the same quality—instead of the 660 million that was used. Obviously, such a surplus of land was not available, and certainly not in Asia, where the population has increased from 1.2 to 3.8 billion over this time period. Moreover, if more environmentally fragile land had been brought into agricultural production, the impact on soil erosion, loss of forests and grasslands, biodiversity and extinction of wildlife species would have been much more severe.

The debate on benefits and shortcomings of the Green Revolution must be framed within the larger context of population growth. The continuing decline in the real price of cereals also needs to be considered. Lower food costs benefit everybody in society but especially the poor consumer. Finally, the very strong growth linkages between Green Revolution technology and industrial development are also apparent. Indeed, much of Asia's spectacular economic development in industry and services over the past 20 years has followed in the wake of the agricultural revolutions that preceded them.

Despite the successes of smallholder Asian farmers in applying Green Revolution technologies to triple cereal production since 1961, millions of miserably poor people remain, especially in South Asia. Huge stocks of grain have accumulated in India over the past several years, while tens of millions need more food but do not have the purchasing power to obtain it. China has been more successful in achieving broad-based economic growth and poverty reduction than India. Nobel Economics Laureate, Professor Amartya Sen, attributes the difference to the greater priority that the Chinese government has given to investments in rural education and health care services (Sen, 2000). Nearly 80% of the Chinese population is literate, whereas only 50% of the Indian population can read and write. Only 9% of Chinese children are malnourished compared with 45% in India. With a healthier and better educated rural population, China's economy has been able to grow about twice as fast as the Indian economy over the past two decades and today China has a per capita income nearly twice that of India.

Africa Is the Greatest Challenge Today

In 1986 I became involved in food crop production technology transfer projects in sub-Saharan Africa (SSA), sponsored by the Nippon Foundation and its Chairman, the late Ryoichi Sasakawa, and enthusiastically supported by former U.S. President Jimmy Carter. Our joint program is known as Sasakawa-Global 2000 and currently operates in 10 SSA countries and, previously, in four other countries.

Working alongside national extension services during the past 16 years, SG 2000 has helped small-scale farmers to grow more than one million demonstration plots, ranging in size from 1,000 to 5,000 square meters. These demonstration plots have been concerned with demonstrating improved technology for basic food crops: maize, sorghum, wheat, rice, cassava, and grain legumes.

The packages of recommended production technology include: (1) the use of the best available commercial varieties or hybrids, (2) proper land preparation and seeding to achieve good stand establishment, (3) proper application of the appropriate fertilizers and, when needed, crop protection chemicals, (4) timely weed control, and (5) moisture conservation and/or better water utilization, if under irrigation. SG 2000 also has helped smallholder farmers to improve on-farm grain storage, both to reduce losses due to spoilage and infestation and to allow farmers to hold stocks longer so that they can sell when market prices are more favorable.

Virtually without exception, demonstration plot yields are 2-3 times higher than the control plots employing the farmer's traditional methods. Hundreds of field days, attended by thousands of farmers, have been organized to demonstrate and explain the components of the production package. In areas where the projects are operating, farmers' enthusiasm is high and political leaders are taking much interest in the program.

While the program clearly has demonstrated the availability of technology to greatly improve yields, sustained adoption by farmers of the recommended technologies has been disappointing. High prices and undeveloped input supply systems—due in large part to poor transport systems—keep most smallholder farmers from purchasing improved seeds, fertilizers, crop protection chemicals, and farm machinery. Similarly, poorly functioning rural finance systems and high interest rates conspire to deprive most farmers of access to production credit.

Restoring Soil Fertility—Many agricultural environments in Africa are fragile ecological systems and some of the oldest geologic landscapes. Few of the deeply weathered soils have been rejuvenated by volcanic ash or glacial action. Under continuous cultivation these soils lose fertility rapidly. In an earlier day, traditional systems of shifting cultivation and complex cropping patterns permitted low-yielding, but relatively stable, food production systems. However, expanding populations and food requirements shortened the bush/fallow periods previously used to restore soil fertility and pushed farmers onto increasingly marginal lands. With more continuous cropping on the rise, organic material and nitrogen have been rapidly depleted from African soils while phosphorus and other nutrient reserves are being depleted slowly but steadily. This is having disastrous environmental consequences.

The magnitude of nutrient mining in SSA is enormous. Estimates have been made that the net per-hectare loss in about 100 million ha of cultivated land during the past 30 years is about 700 kg of nitrogen, 100 kg of phosphorus, and 450 kg of potassium (Sanchez et al., 1996). In marked contrast, soil nutrient levels on farms in North America and Europe have increased over this same time period (sometimes resulting in groundwater and stream pollution). The soil nutrient losses in SSA are an environmental, social, and political time bomb. Unless we wake up soon and reverse these disastrous trends, the future viability of African food systems will indeed be imperiled.

Table 3. Fertilizer Nutrient Consumption Per Hectare of Arable Land in Selected Countries, 2000

	kg			kg
Uganda	1		Cuba	37
Ghana	3		South Africa	51
Guinea	4		India	103
Mozambique	4		U.S.A	105
Tanzania	6		Brazil	140
Nigeria	7		France	225
Burkina Faso	9		China	279
Mali	11		UK	288
Ethiopia	16		Japan	325
Malawi	16		Vietnam	365
Benin	18		Netherlands	578

Source: FAOSTAT, July 2002.

While farmers should endeavor to use all of the organic nutrients that are economically feasible—not only to replenish nutrients but to improve overall soil structure and health—there simply are not enough organic manures and crop residues available to replenish and maintain soil fertility in these potentially higher yielding production systems needed to meet growing food requirements and reduce poverty.

It makes no biological difference to the plant whether the nitrate ion it "eats" comes from a bag of fertilizer or decomposing organic matter. Moreover, given the very low current levels of fertilizer use and the alarming trends in declining soil fertility, a very strong case can be made that increased fertilizer use in SSA is one of the most "environmentally friendly" things we can do. We need to shift the debate to how best to supply adequate plant nutrients in the most efficient way possible.

Increased consumption of chemical fertilizer is absolutely essential in SSA. At present only about 9 kg of nutrients per hectare are used—and only half this amount probably on food crops—compared with rates 10-20 times greater in most developing countries of Asia and the industrialized nations (Table 3).

The SG 2000 field program has been grappling with the soil fertility problem for 16 years. Various strategies have been pursued, including split applications and incorporation of fertilizers to maximize use efficiency; timely weeding; introduction of green manures, grain legumes and nitrogen-fixing shrubs and trees into rotations with cereals and roots and tubers; and buildup of organic matter in the soil profile through mulches. These sorts of integrated approaches can increase soil organic matter and improve soil fertility, while reducing the outlays needed for purchased fertilizers. However, we also must be realistic. Without phosphate on some of these soils, you can't even produce weeds. And many of the so-called "organic" approaches may be too labor intensive for farmers to apply widely to the main field crops. Thus, chemical fertilizers must be placed at the center of soil fertility restoration and management strategies in Africa. But, in most countries, expanding chemical fertilizer use is given second priority.

Even if fertilizer use rates were doubled or tripled over the next two decades, consumption in SSA per hectare of arable land would still lag far behind all other agricultural regions in the world. In order for fertilizer consumption to increase, the profitability of its use must be improved. There are only two ways this can happen. The best solution is to improve the efficiency of fertilizer supply systems, which will reduce prices. However, at the present time market failures exist all along the supply chain that contributes to the final farm-gate fertilizer price in SSA. In most Africa countries, fertilizer prices are 2-4 times higher than those found elsewhere. Although higher prices will inevitably continue in the near term—because of poor transport infrastructures and relatively low trade volumes—much can be done to reduce costs through improved policies and supply practices.

Fertilizer consumption is roughly the same in 2000 as it was in 1985. Unless SSA's dysfunctional and fragmented fertilizer supply systems can be righted, some sort of public intervention must be considered. Africa's soils, and its impoverished food-insecure farmers, cannot wait forever for the market mechanism to work. I recognize the danger of subsidies, in that they are costly and the allocation process becomes politically driven, rather than market driven (IFDC, 2003c). However, I believe that targeted subsidies—such as the successful voucher programs that IFDC has helped to design and implement in Bangladesh, Albania, Kosovo, Afghanistan, and now in Malawi—for very poor farmers and in highly degraded landscapes and watersheds, deserve serious consideration by policymakers and donors.

Overcoming the Infrastructure Bottleneck— Efficient transport is the life-blood of economic modernization. It is essential to improve agricultural productivity and enable farmers to bring their products to markets. Intensive agricultural production is especially dependent upon access to vehicles at affordable prices.

For example, a ton of maize can be shipped from a U.S. farm to Mombassa, some 11,000 km away, for a total of US $50. To transport that ton from Mombassa to Kampala, Uganda—less than 1,000 km inland—would cost $80-$90/ton. To ship it another 300 km to a provincial capital, Mbarara, would cost another $30-$35/ton, for a total of $120-$125/ton, which is nearly three times the cost of shipping a ton of maize from a farm in the United States to Mombassa—a distance seven times greater.

Unfortunately, most agricultural production in Africa still is generated along a vast network of footpaths, tracts and community roads, where the most common mode of transport is "the legs, heads, and backs of women." Indeed, the largest part of a household's time expenditure is for domestic transport. This situation places farmers in a double cost/price squeeze—between high farm-gate costs for inputs and low farm-gate prices for output.

Efforts to modernize African agriculture have been stymied by these very high marketing costs, which are the highest in the world. In large part this is because the kilometers of paved roads per capita in Africa are the lowest in the world (Table 4). Uganda only has 94 km per one million people, Ethiopia 66 km, Mozambique 141 km, compared with 1,064 km in Brazil, 1,586 km in Zimbabwe, 12,987 km in France, and 20,987 km in the United States. Of course, there are many miles of unpaved roads in Africa. These need to be upgraded to all-weather status, which can be achieved with gravel and suitable grading and drainage.

Table 4. Kilometers of Paved Roads Per Million People in Selected Countries Around the World

	km			km
U.S.A	20,987		Guinea	637
France	12,673		Ghana	494
Japan	9,012		Nigeria	230
Zimbabwe	1,586		Mozambique	141
South Africa	1,402		Tanzania	114
Brazil	1,064		Uganda	94
India	1,004		Ethiopia	66
China	803		Congo, DR	59

Source: *Encyclopedia Britannica, 2002 Yearbook.*

Finding ways to provide effective and efficient infrastructure (roads, potable water, and electricity) in SSA underpins all other efforts to reduce poverty, improve health and education, and secure peace and prosperity. Not only will improved rural infrastructure increase agricultural productivity and spur economic development, it will reduce rural isolation, thus helping to break down ethnic animosities and allow the establishment of rural schools and clinics in areas where teachers and health care workers have heretofore been unwilling to venture.

To date, although all governments provide lip service about the importance of agriculture, few have given priority to agriculture and rural development. Indeed, most governments have reduced their funding for agriculture. Over the past 10-15 years, the hope had been that the private sector would fill the void of a retreating public sector. This has not happened, nor will it while political and economic instability continues. Moreover, so far, the forces of globalization have brought few, if any, benefits to SSA. Traditional exports, such as cocoa, coffee, and palm oil, have been hobbled by depressed world prices and increasing competition from Asian countries. Some progress has been made in expanding non-traditional exports, especially in fruits and vegetables, in a few countries (e.g., Kenya). But losses in market share in traditional crops (including cotton and sugar cane) outweigh gains made in developing non-traditional export markets.

In July 2002, Africa's heads of state formally adopted a new development strategy, called the New Partnership for Africa's Development (NEPAD). This initiative provides a strategic framework for interventions within the African Union. NEPAD expects the international community to support Africa's plan for self-development and not to prescribe a plan for Africa. The donor community expects African governments to exert peer review, taking action against rogue states and agreeing to meet performance standards as a basis for providing and continuing international aid.

African heads of state have selected agriculture as one of the top priorities for immediate implementation. NEPAD has the rough outlines of a plan, called the Comprehensive Africa Agriculture Development Plan (CAADP), which is built around four "pillars" of activities: (1) land and water reclamation and management, (2) infrastructure and markets, (3) food producing and reducing hunger, and (4) institutions, especially research and extension (NEPAD, 2003). More than 30 CAADP programs and projects have been designed and project proposals are being prepared.

African leaders will have to show competence in developing the CAADP. Donor financing will be much more mindful of the governance process, requiring a higher standard of performance than in the past. African governments have pledged to increase national contributions to the overall agricultural development budgets from 35% to 55% (i.e., by 50%), so that they will have more of a direct stake.

Future Increases in Food Demand

Increases in population and wealth will largely determine future increases in food demand. Overall, the UN predicts that world population will grow to 7.2 billion by 2015, 8.3 billion by 2030, and 9.3 billion by 2050 (FAO, 2002). I think these numbers are a bit conservative and that world population could easily surpass 10 billion by 2050 before leveling off at around 11 billion later in this century. Almost all of the growth will occur in the developing countries, with SSA posting the greatest gains, even with the HIV/AIDs pandemic, followed by South Asia.

Cereals will continue to be the dominant food and feed crops. An additional 1 billion tons will be needed by 2030, with feed use increasing from one-third of total cereal demand to 40%. Cereal demand overall in the developing countries is expected to significantly outpace supply, with net imports increasing from 109 to 265 million tons by 2030 (FAO, 2002). Future per capita consumption of oil crops is expected to rise more rapidly than in cereals. Per capita consumption of livestock products could increase by more than 40% by 2030, with poultry and swine consumption growing the fastest (FAO, 2002; Delgado et al., 1999).

Sources of Future Increases in Food Supplies

Most increases in the global food supply in the decades ahead must come from agricultural lands already in production. Indeed, more than 85% of total growth in cereal production must come from increasing yields on lands already in production (IFPRI, 2002). Such productivity improvements will require varieties with higher genetic yield potential and greater tolerance of drought, insects and diseases. To achieve these genetic gains, advances in both conventional and biotechnology research will be needed. In crop management, we can expect productivity improvements in soil and water conservation, tillage, fertilization, weed and pest control, and postharvest handling.

Raising Maximum Genetic Potential

The slowing of gains in maximum genetic yield potential is a matter of considerable concern. 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, wheat, and maize research, changes in plant architecture, hybridization, and wider genetic resource utilization are being pursued to increase genetic maximum yield potential. Significant progress has been made in all three areas. New types of "super rice" with fewer—but highly productive—tillers are being developed in Asia (Kush, 1995). 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%. New wheat 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 best current germplasm (Rajaram and Borlaug, 1997).

The success of hybrid rice in China (now covering more than 50% of the irrigated area) has led to a renewed interest in hybrid wheat, when most research worldwide had been discontinued for various reasons. Recent improvements in chemical hybridization agents, advances in biotechnology, and the emergence of the new wheat plant type have made a reassessment of hybrids worthwhile. With better heterosis and increased grain filling, the yield frontier of wheat could be shifted 25%-30% higher.

In maize, yield increases have been achieved by breeding plants that can withstand higher planting densities, as well as the shift to single cross hybrids. Maize production has really begun to take off in many Asian 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. Recent developments with high-yielding quality protein maize (QPM) varieties and hybrids also stand to improve the nutritional quality of the grain without sacrificing yields. This achievement offers important nutritional benefits for livestock and humans. Large gaps exist between experimental and smallholder farmer yields throughout the developing world, and especially in Africa. These gaps can be closed.

Potential for Land Expansions

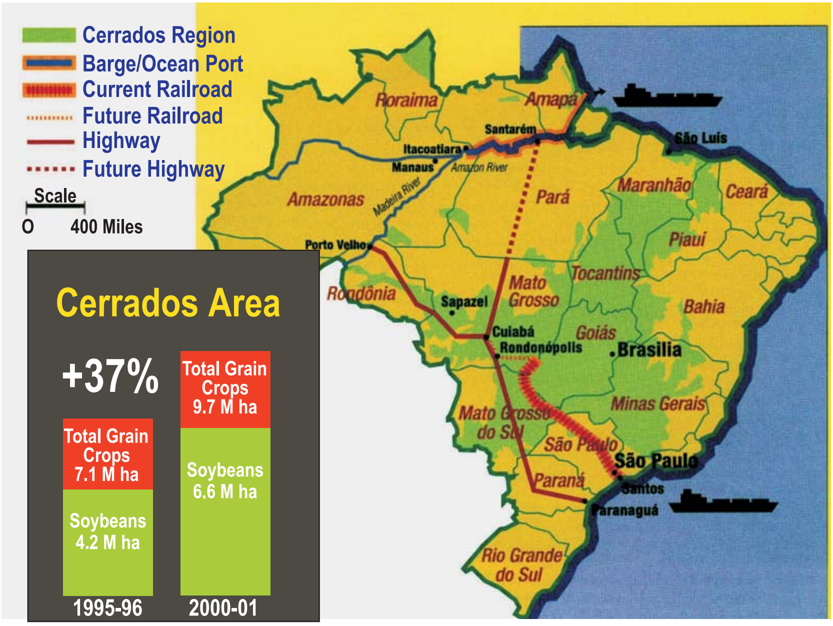
The potential for further expansion in the global arable land area is limited for most regions of the world. This is certainly true for densely populated Asia and Europe. Only in SSA and South America do large unexploited tracts exist, and only some of this land should eventually come into agricultural production. In populous Asia, home to more than half of the world's people, there is very little uncultivated land left. Indeed, some of the land, especially in South Asia, currently in production should be taken out of cultivation, because of high susceptibility to soil erosion.

Bringing the world's unexploited potentially arable lands into agricultural production poses formidable challenges. The Brazilian *Cerrado,* or acid savanna, is a good case in point. The *Cerrado* is a vast expanse of mostly flat to slightly rolling grasslands, with fire-induced semi-climax brush and stunted-tree ecotypes in some areas. Its total area is approximately 205 million ha, approximately equivalent to the combined area of Spain, France, Italy and Britain. It spans a geographic area from latitude 24° to 4° S and varies in elevation from 500 m to 1,800 m, with unimodal precipitation (October to March) varying from 900 to 1,800 mm annually (see map).

The central *Cerrado*, with 175 million ha in one contiguous block, forms the bulk of the savanna lands. Approximately 112 million ha 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. They are strongly acidic, have toxic levels of soluble aluminum (and of manganese in some areas); most of the phosphate is fixed and unavailable.

Until 50 years ago, the *Cerrado* was sparsely inhabited and considered to be essentially worthless for agriculture. Some agriculture was practiced on strips of alluvial soils along the margins of streams, which were less acidic and where there had been an

Brazilian Cerrados



Source: Top Producer, *Farm Journal Media*, 2001.

accumulation of nutrients. In addition, there was some cattle production, but the natural savanna/brush flora (poor digestibility and nutritive quality) resulted in low carrying-capacity production.

Today, a great agricultural revolution is under way in the *Cerrado*, the result of a long process of research and development. Bits and pieces of research information on soils and agronomy and some aluminum-tolerant plant germplasm were developed during the 1930s and 1940s at various agricultural universities and provincial and federal government experiment stations. By the late 1960s, farming was being attempted in some parts of the *Cerrado* on a commercial scale as soil amendments began to be applied—liming to correct acidity and aluminum toxicity, combined with NPK, sulfur, and micronutrient fertilizers. A new generation of crop varieties (forage grasses, rice, soybean, maize, and wheat) was developed that possessed tolerance to aluminum toxicity. Unfortunately, this first group of varieties, although tolerant to aluminum toxicity, had low grain yield potential and other defects, especially susceptibility to various diseases.

The creation in 1973 of the Empresa Brasileira de Pesquisa Agropecuaria (EMBRAPA)—the national Brazilian Agricultural Research Corporation—provided a significant impetus to research aimed at the *Cerrado*. EMBRAPA scientists initiated a systematic program of interdisciplinary research, integrating past knowledge and generating new research information and products. Much of the soil fertility/toxicity research and interdisciplinary agronomic research was centered at the Centro de Pesquisa Agropecuaria del Cerrado (CPAC), located near Brasilia, while the research on breeding of improved crop varieties with disease and insect resistance was carried out at various EMBRAPA commodity-specific national research centers.

During the 1980s, EMBRAPA and several international agricultural research centers (especially CIMMYT and CIAT) began more intensive collaboration to develop a third generation of crop varieties combining tolerance to aluminum toxicity with high yield, better resistance to primary diseases, and better agronomic type. There are good varieties with aluminum tolerance in the case of rice, maize, soybeans, wheat and several species of pasture grasses, including panicums, pangola, and vaqueria. Triticale is an interesting man-made cereal that has a very high level of tolerance to aluminum. However, up to the present time, it has not been widely used in the *Cerrado,* either for forage or for grain production.

There are many research challenges in the present situation of commercial crop production in the *Cerrado* that are still unfolding. Many advances are being made by farmer associations, both alone and in collaboration with scientists. Much more needs to be done and more research is needed, both by public and private sector organizations.

Further research is needed to develop the more exact fertilizer recommendations for different crops in the different areas. Since the zero tillage or minimum tillage is in widespread use, whereby the plant refuse or plant residue is left on the surface, it will be absolutely necessary to work out better crop rotations to minimize the foliar infection with diseases that result from inoculums remaining in the plant crop residue from the previous season or two.

Huge investments are being made to develop transport systems from the *Cerrados* to the ocean-going ports. Roads, railroads and barge systems will soon link much of the *Cerrados* to ports and greatly reduce transport costs, which has been a major obstacle to full economic development.

If the improved technology currently available was used now on the 20 million ha of potentially arable rainfed land in the *Cerrado,* it would be possible for farmers to attain 3.2 tons/ha average yield and 64 million tons of production. The irrigated area could also be increased tenfold—to 5 million ha—with an expected average yield of 6 tons/ha, for a total crop production of 30 million tons. The meat production could also be increased fourfold with improved pastures. In total, food production could be tripled, from the 30 million tons today to nearly 100 million tons, through widespread adoption of improved technology already available (Table 5).

The opening of the *Cerrado* will help ensure adequacy in world food supply for the next two decades if we continue to use wise policies to stimulate production. Eventually, the technology similar to what made the *Cerrados* productive will move into the *llanos* in Colombia and Venezuela and hopefully into central and southern African countries where they have similar soil problems.

Water Availability and Management

Irrigated agriculture—which accounts for 70% of global water withdrawals—covers some 17% of cultivated land (about 275 million ha) yet accounts for nearly 40% of world food production. The rapid expansion in world irrigation and in urban and industrial water uses has led to growing shortages. Indeed, the UN's 1997 Comprehensive Assessment of the Freshwater Resources of the World estimates that, by the year 2025, as much as two-thirds of the world's population could be under stress conditions (WMO, 1997).

Clearly, we need to rethink our attitudes about water and move away from thinking of it as 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 and industrial 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 farmers.

There are many technologies for improving the water use efficiency in agriculture. Wastewater can be treated and used for irrigation, especially important for peri-urban agriculture, which is growing rapidly around many of the world's mega-cities. New crops requiring less water (and/or new improved varieties), more efficient crop sequencing, and timely planting can also achieve a significant saving in water use.

Proven technologies are also available that save water, reduce soil salinity, and increase water pro-

Table 5. Potential Food Production if Technology Available in 1995 Is Adopted on Cerrado Area Already in Production

Land Use	Area	Productivity	Production
	(million ha)	(t/ha/year)	(million tons)
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

Source: J. Macedo CPAC, EMBRAPA, 1995.

ductivity (yield per unit of water used). Various new precision irrigation systems—like drip and sprinkler systems—are available that will supply water to plants only when they need it. Technologies such as planting on raised beds or conservation (zero) tillage also use water more efficiently, especially in irrigation. Improved small-scale and supplemental irrigation systems also are now available to increase the productivity of rainfed areas, which offer much promise for smallholder farmers.

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" to complement the so-called "Green Revolution" of the 20th century. In the new Blue Revolution, water-use productivity must be wedded to land-use productivity. New science and technology must lead the way.

Marginalized People and Lands

Of the 800 million hungry and malnourished people in the developing world, 232 million are in India, 200 million in sub-Saharan Africa, 112 million in China, 152 million elsewhere in Asia and the Pacific, 56 million in Latin America, and 40 million in the Near East and North Africa (UN Millennium Project, 2003). Of the total number of hungry, about 214 million, or 26%, have caloric intakes so low that they are unable to work or care for themselves. At least half of the world's most food-insecure people are poor smallholder farmers in low-income countries that cultivate marginal lands that are environmentally fragile, and rely on natural resources over which they have little legal control. Land-hungry farmers result to cultivating such unsuitable areas as erosion-prone hillsides and semiarid areas (where soil erosion is rapid) and tropical forests (where crop yields on cleared fields drop sharply after just a few years). Many of these marginal lands are not only critical to livelihoods of very poor people they also play critical roles in watershed and biodiversity conservation. Moreover, the poor are the most vulnerable to the impacts of ecosystem degradation. If they are to eat, most of these people will have to produce the food they need themselves (UNDP, 2003).

These statistics on hunger point to the need to improve drastically the food security of farmers in higher-risk environments and remote regions—to bring the Doubly Green Revolution that Rockefeller Foundation President Gordon Conway talks about (Conway, 1999). The statistics also point to the need to develop poverty-reduction strategies that will provide employment options for the very resource-poor farmers, especially in marginal lands, in sectors other than agriculture.

Clearly, too many people in the developing world are trying to gain their livelihoods through agriculture, with too few resources. Reducing agricultural populations—and increasing the land and water resources available to those that remain—will be one of our greatest 21st century challenges. Public works projects to improve the infrastructure and environment are also needed if hunger is to be halved. Often, these social investments will be part-time employment for smallholder farmers during the "lean season."

Food-for-work programs would be organized with rural agricultural communities in highly environmentally degraded areas to initiate high-priority eco-conservation reclamation works, such as gully rehabilitation, bunds and terraces, and tree planting, including nitrogen-fixing and nutrient-mobilizing species. In-kind food payments could be sourced from domestic production in food-surplus areas of the country. Thus, multiple development goals could be accomplished: reclamation of severely degraded watersheds, increased food security and expanded market demand for domestically produced food staples.

Security in Land Tenure

Farming and ranching are primary sources of wealth in agricultural societies. Unequal and insecure systems of land tenure are major causes of poverty and civil unrest in the developing world. Poor people need secure access to land through individual or community ownership, long-term rights, functioning rental markets, or some other means. Increasing women's access to secure tenure arrangements is especially needed. Traditional systems of land tenure often discourage farmers from investing in land improvements, since the fruits of investments in fencing, land terracing, and water harvesting and irrigation are not guaranteed. In many areas, traditional pasture rights also conspire against investments in land conservation, leading to growing tensions between pastoralists and agriculturalists. Population pressures—human and livestock—are leading to over-grazing and soil degradation which, in turn, lead to conflicts over land access, as both farmers and pastoralists need to expand their operations to lands.

The Peruvian economist Hernando de Soto and his colleagues at the Institute of Liberty and Democracy (ILD) in Lima, Peru, have been leaders in studying what he calls, "the mystery of capital." What their research has found is that the world's poor have accumulated all the assets needed for escaping poverty (De Soto, 2000). Indeed, he contends that the value of their savings is many times all the foreign aid and investment received since 1945. However, he contends, the poor hold their assets in defective forms—they lack adequately documented and recorded property rights. As a result their assets cannot readily be turned into capital, cannot be traded outside of narrow local circles, and cannot be used as collateral for a loan or a share against an investment.

What to Expect From Biotechnology?

In the last 20 years, biotechnology based upon recombinant DNA has developed invaluable new scientific methodologies and products in food and agriculture. This journey deeper into the genome—to the molecular level—is the continuation of our progressive understanding of the workings of nature. Recombinant DNA methods have enabled breeders to select and transfer single genes, which has not only reduced the time needed in conventional breeding to eliminate undesirable genes but also allowed breeders to access useful genes from other distant taxonomic groups. So far, these gene alterations have conferred producer-oriented benefits, such as resistance to pests, diseases, and herbicides. Other benefits likely to come (through biotechnology and conventional plant breeding) are varieties with greater tolerance of drought, waterlogging, heat and cold—important traits given current predictions of climate change. In addition, many consumer-oriented benefits, such as improved nutritional and other health-related characteristics, are likely to be realized over the next 10-20 years.

Following are two of my own dreams for biotechnology. Among all the cereals, rice is unique in its immunity to the rusts (*Puccinia* spp.) All the other cereals—wheat, maize, sorghum, barley, oats, and rye—are attacked by two to three species of rusts, often resulting in disastrous epidemics and crop failures. Enormous scientific effort over the past 80 years has been devoted to breeding wheat varieties for resistance to stem, leaf, and yellow rust species. After many years of intense crossing and selecting and multi-location international testing, a good, stable, but poorly understood, type of resistance to stem rust was identified in 1952 that remains effective worldwide to the present. However, no such success has been obtained with resistance to leaf or yellow rust, where genetic resistance in any particular variety has been short-lived (3-7 years). Imagine the benefits to humankind if the genes for rust immunity in rice could be transferred into wheat, barley, oats, maize, millet, and sorghum. Finally, the world could be free of the scourge of the rusts, which have led to so many famines over human history.

On another front, bread wheat has superior dough for making leavened bread and other bakery products due to the presence of two proteins—gliadin and glutenen. No other cereals have this combination. Imagine if the genes for these proteins could be identified and transferred to the other cereals, especially rice and maize, so that they, too, could make good-quality "leavened" bread. This would help many countries, especially the developing countries in the tropics—where bread wheat flour is often the single largest food import—to save valuable foreign exchange.

Despite the formidable opposition in certain circles to transgenic crops, commercial adoption by farmers of the new varieties has been one of the most rapid cases of technology diffusion in the history of agriculture. Between 1996 and 2002, the area planted commercially to transgenic crops has increased from 1.7 to 58.7 million ha (James, 2003).

Although there have always been those in society who resist change, the intensity of the attacks against GMOs by certain groups is unprecedented, and in certain cases, even surprising, given the potential environmental benefits that such technology can bring in reducing the use of crop protection chemicals. It appears that many of the most rabid crop biotech opponents are driven more by a hate of capitalism and globalization than by the actual safety of transgenic plants. However, the fear they have been able to generate about biotech products among the public is due in significant measure to the failure of our schools and colleges to teach even rudimentary courses on agriculture. This educational gap has resulted in an enormous majority, even among well-educated people, who seem totally ignorant of an area of knowledge so basic to their daily lives and, indeed, to their future survival. We must begin to address this ignorance without delay—especially in the wealthy urban nations—by making it compulsory for students to study more biology and to understand the workings of agricultural and food systems.

Much of the current debate about transgenic crops in agriculture has centered around two primary issues—safety and concerns of access and ownership. Part of the criticism about GMO safety holds to the position that introducing “foreign DNA” into our food crop species is unnatural and thus an inherent health risk. Since all living things—including food plants, animals, and microbes—contain DNA, how can we consider recombinant DNA to be unnatural? Even defining what constitutes a “foreign gene” is also problematic because many genes are common across many organisms.

Almost all of our traditional foods are products of natural mutation and genetic recombination, which are the drivers of evolution. Without this ongoing process, we would probably all still be slime on the bottom of some primeval sea. In some cases, Mother Nature has done the genetic modification, and often in a big way. For example, the wheat groups we rely on for much of our food supply are the result of unusual (but natural) crosses between different species of grasses. Today’s bread wheat is the result of the hybridization of three different grasses, each containing a set of seven chromosomes and, thus, could easily be classified as transgenic. Maize is another crop that is the product of transgenic hybridization (probably of *Teosinte* and *Tripsacum*).

Several hundred generations of farmers have accelerated genetic modification through recurrent selection of the most prolific and hardiest plants and animals. To see how far the evolutionary changes have come, one needs only to look at the 5,000-year-old fossilized maize cobs found in the caves of *Tehuacan* in Mexico, which are about 1/10 the size of modern maize varieties. Over the past 100 years or so, scientists have been able to apply an increased understanding of genetics, agronomy, plant physiology, pathology, and entomology to accelerate the process of combining high genetic yield potential with greater yield dependability under a broad range of biotic and abiotic stresses.

Obviously, it does make sense for GM foods to carry a label if the food is substantially different from similar conventional foods. This would be the case if there is a nutritional difference or if there is a known allergen or toxic substance in the food. If the food is essentially identical to regular versions of the same food, what would be the utility? To me, this would undermine the central purpose of labeling, which is to provide useful nutritional or health-related information to allow consumers to make “informed” choices.

On the environmental side, I find the opposition to the transgenic crops carrying the *Bacillus thuringiensis* (Bt) gene to be especially ironic. Rachel Carson, in her provocative 1962 book, *Silent Spring*, was especially effusive in extolling the virtues of Bt as a “natural” insecticide to control caterpillars. But anti-GMO activists have decried the incorporation of the Bt gene into the seed of different crops, even though this can reduce the use of insecticides and is harmless to other animals, including humans. Part of their opposition is based upon the prospect that widespread use of Bt crops may lead to mutations in the insects that eventually will render the Bt gene ineffective. This assertion seems incredibly naïve about host:pathogen relationships. Indeed, we can be quite sure that the ability of a particular strain of *Bacillus thuringiensis* to confer insect resistance inevitably will break down, and this is why dynamic breeding programs—using both conventional and recombinant DNA techniques—are needed to develop varieties with new gene combinations to keep ahead of mutating pathogens. This has been the essence of plant-breeding programs for more than 70 years.

Of course, scientists and researchers employing recombinant DNA must pay attention to public values and concerns and must explore all legitimate and reasonable questions about the potential impacts of their activities. However, today we are seeing too many opponents of biotechnology dismiss the many safety and regulatory checks that govern whether a new product is brought to the marketplace. Unfortunately, they willfully choose to emphasize highly unlikely potential risks.

In the United States, at least three Federal agencies provide scrutiny over the safety of GMOs—the U.S. Department of Agriculture (USDA), which is responsible for seeing that the plant variety is safe to grow; the Environmental Protection Agency (EPA), which has special review responsibilities for plants that contain genes that confer resistance to insects, diseases, and herbicides to protect against adverse environmental effects; and the Food and Drug Administration (FDA), which is responsible for food safety. The data requirements imposed upon biotechnology products are far greater than they are for products from conventional plant breeding, and even from mutation breeding, which uses radiation and chemicals to induce mutations. But we must also understand that there is no such thing as "zero biological risk." It simply doesn't exist, which makes, in my opinion, the enshrinement of "precautionary principle" just another ruse by anti-biotech zealots to stop the advance of science and technology.

There is no reliable scientific information to date to substantiate that GMOs are inherently hazardous. Recombinant DNA has been used for 25 years in pharmaceuticals, with no documented cases of harm attributed to the genetic modification process. So far, this is also the case in GM foods. This is not to say that there are no risks associated with particular products. There certainly could be. But we need to separate the methods by which GMOs are developed—which are not inherently unsafe—from the products, which could be if certain toxins or allergens are introduced.

There certainly have been errors in the GMO certification process. A recent example was the "restricted" approval in the United States by the EPA of a Bt maize hybrid, Starlink, for use only as an animal feed because of possible allergenic reaction that this strain of Bt might have in humans. EPA granted this approval knowing full well that marketing channels did not exist to segregate maize destined for animal feed from that destined for human consumption. As a result, Starlink maize got into various corn chips and taco shells, and undermined public confidence. Lost in the furor, however, was the fact that there was little reason to believe that the maize was actually unsafe for human consumption—only an unsubstantiated fear that it might cause an allergic reaction. Subsequently, a blue-ribbon scientific panel confirmed that Starklink maize was safe for human consumption. Still, it has now become policy that no variety will be released without approval for both food and feed uses.

A second controversial aspect of transgenic varieties involves issues of ownership and access to the new products and processes. Since most of GMO research is being carried out by the private sector, which aggressively seeks to patent its inventions, the intellectual property rights issues related to life forms and to farmer access to GM varieties must be seriously addressed. Traditionally, patents have been granted for "inventions" rather than the "discovery" of a function or characteristic. How should these distinctions be handled in the case of life forms? Moreover, how long, and under what terms should patents be granted for bioengineered products?

The high cost of biotechnology research also appears to be leading to a rapid consolidation in the ownership of agricultural life science companies. Is this desirable? I must confess to uneasiness on this score and believe that the best way to deal with this potential problem is for governments to ensure that public sector research programs are adequately funded to produce "public goods." By this I mean fully funded public sector research, which is quite different from the "commissioned" research that public institutions are now doing for private companies.

Unfortunately, during the past two decades, support to public national research systems in the industrialized countries has seriously declined, whereas support for international agricultural research has dropped so precipitously to border on the disastrous. If these trends continue, we risk losing the broad continuum of agricultural research organizations—both public and private and from the more-basic to the more-applied—which are needed to keep agriculture moving forward. We need to ensure that farmers and consumers never become hostages to possible private sector monopolies. So, yes, I am all for private sector research and believe that private companies need to be fairly compensated for their research investments and have their intellectual property protected. But the public sector must always retain a moderating hand, in order to ensure that the public good continues to be served and also to educate and train future generations of scientists.

Agriculture and the Environment

The current backlash against agricultural science and technology evident in some industrialized countries is hard for me to comprehend. Thanks to science and technology that has permitted increasing yields on the lands best suited to agriculture, world farmers have been able to leave untouched vast areas of land for other purposes.

Had the U.S. agricultural technology of 1940—when relatively little chemical fertilizer and agricultural chemicals were used—still persisted today we would have needed an additional 233 million ha (575 million acres) of agricultural lands—of the same quality—to match 1997-98 average production of 700 million tons for the 17 main food and fiber crops produced in the United States (Figure 4). The area spared for other land uses is slightly greater than all the land in 25 states east of the Mississippi River.

If the 1950 average global cereal grain yield had still prevailed in 1998, instead of the 600 million ha that were used for production, we would have needed nearly 1.8 billion ha of land of the same quality to produce the current global harvest (Figure 5). This amount of land generally was not available, especially in highly populated Asia. Moreover, had more environmentally fragile land been brought into agricultural production, the impact on soil erosion, loss of forests, grasslands, and biodiversity, and extinction of wildlife species would have been enormous.

The attacks against chemical fertilizers are also difficult to understand. Biochemically, it makes no difference to the plant whether the nitrate ion it "eats" comes from a bag of fertilizer or decomposing organic matter. Yet, to hear many uninformed people, chemical fertilizer is seen more as a poison than the plant food that it really is. Equally misinformed is the notion that "organically" produced food has higher nutritive value. This is not so. Although 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. Indeed, it would be impossible for organic sources to replace the 80 million tons of nitrogen contained in chemical fertilizer. If we tried to do it with cattle manure, the world beef population would have to increase from about 1.5 billion to 6-7 billion head, with all of the resulting overgrazing, erosion and destruction of wildlife habitat this would cause. It would produce quite a heap of animal dung, too, and quite an aroma!

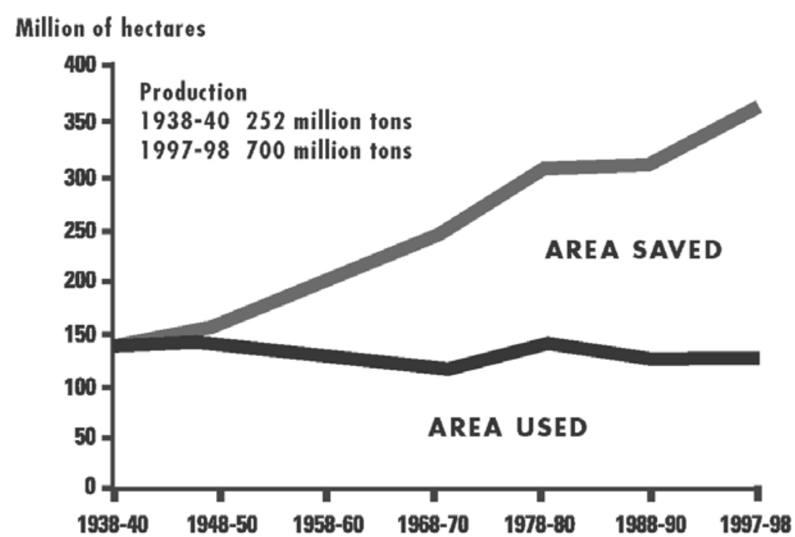
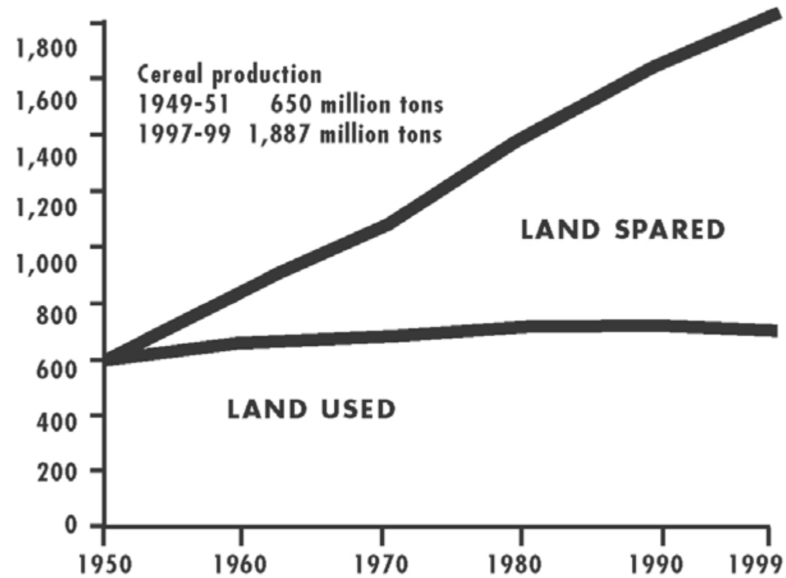


Figure 4. U.S. Total Crop Area Spared by Application of Improved Technology on 17 Food, Feed, and Fiber Crops in Period 1938-40 to 1997-98



*Uses milled rice equivalents.

Source: FAO Production Yearbooks and AGROSTAT.

Figure 5. World Cereal* Production—Areas Saved Through Improved Technology, 1950-99

One might have thought that GMOs would have been warmly received by the green movement. So far, in cotton, maize and soybeans alone in the United States, pesticide use has been reduced by 21,000 tons due the use of varieties with insect resistance and herbicide tolerance. These reductions in pesticide use have increased farmer income by US $1.5 billion (Gianessi, 2002).

In the not too distant future—when science rather than emotions and ideology becomes more dominant—I predict that many environmentalists will embrace GMOs as a powerful "natural" tool to achieve greater environmental protection.

Agriculture and Peace

Almost certainly, the first essential component of social justice is adequate food. And yet there are almost 1 billion people who go to bed every night hungry. Particularly disheartening are the 150 million young children who go hungry each day, with this undernourishment often leading to irreversible damage to their bodies and minds.

Of the developing countries with the lowest undernourishment, only 8% were mired in conflict. In contrast, of those countries where more than half of the population was underfed, 56% were experiencing civil conflict (FAO, 1999). Since agriculture provides employment for most people in low-income developing countries, it is not surprising that when this sector is allowed to falter, armed conflict often ensues.

It is troubling to see the persistence of large military budgets around the world, including in the United States. In total something on the order of US $800 billion is spent annually on the military. The United States accounts for half of this total (about US $400 billion) and spends 40 times more on the military than it does on overseas development assistance. Indeed, trends in foreign assistance for agricultural and rural development have been declining, not only in the United States but also in many other donor countries and institutions as well. In 2000, the World Bank reported its lowest level of support to agriculture in its history.

One of my fondest dreams would be to see the achievement of primary education for all and the elimination of gender inequalities in secondary education. Still today, an estimated 120 million primary age children do not go to school and 870 million adults—nearly two-thirds of them women—cannot read and write. What a waste! If we are to reduce poverty, control population growth, and build a more equitable global society, such disparities must be narrowed.

Free universal primary school education, especially if this is tied to publicly-supplied school lunch programs and primary health care services, can do much to alleviate poverty. For $50 a child can be provided a nutritious meal every day of the school year, one which is supplied from local food sources (Millennium Development Project, 2003). For $35 a year, a child can also be supplied with minimum health care (UNDP, 2003).

Closing Comments

Thirty-three 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. This has happened. But I also 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. Improvements in crop productivity can be made all along the line—in tillage, water use, fertilization, weed and pest control, and harvesting. Both conventional breeding and biotechnology research will be needed to ensure that the genetic improvement of food crops continues at a pace sufficient to meet growing world populations.

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, vociferous, 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.

Only around 4% of the population in industrialized countries (less than 2% in the United States) is directly engaged in agriculture. With low-cost food supplies and urban bias, is it any wonder that consumers don't understand the complexities of reproducing the world food supply each year in its entirety and expanding it further for the 80 million additional people that are added annually. I believe we must seek to redress this "educational gap" in industrialized urban nations by making it compulsory in secondary schools and universities for students to take courses on biology and science and technology policy.

In conclusion, permit me to leave you with this thought, so eloquently expressed by Andre and Jean Mayer, two American nutritionists, in an article, *Agriculture—The Island Empire*, published in 1974 in the journal *Daedulus* of the American Academy of Arts and Sciences.

> *Few scientists think of agriculture as the chief or the model science. Many, indeed, do not consider it a science at all. Yet it was the first science—the mother of all sciences; it remains the science that makes human life possible; and it may well be that, before the century is over, the success or failure of science as a whole will be judged by the success or failure of agriculture.*

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Norman E. Borlaug

Norman E. Borlaug was born in Iowa 89 years ago. In 1970 he was awarded the Nobel Peace Prize for his lifetime work to feed a hungry world, a prerequisite for peace. He is credited with saving more lives than any person who has ever lived. Although a scientist with outstanding contributions, perhaps Dr. Borlaug's greatest achievement has been his unending struggle to integrate the various streams of agricultural research into viable technologies and to bring agricultural research advances to fruition in farmers' fields.

Born and raised in Cresco, a small farming community in northeast Iowa, Borlaug is of Norwegian descent. He learned his work ethic on a small mixed crop and livestock family farm and obtained his initial education in a one-room rural school house.

His skills as an athlete"mainly in wrestling" opened the path for him to attend the University of Minnesota, where he studied to be a forester, wrestled, and worked various odd jobs. After graduation with a B.Sc. in 1937, he went to work for the U.S. Forest Service, initially in Idaho and later in Massachusetts and Connecticut. He returned to graduate school at the University of Minnesota and took up the study of plant pathology, receiving his Ph.D. in 1942. He then worked as a Microbiologist for E.I. Dupont de Nemours, until being released from his wartime service.

In 1944, he joined the Rockefeller Foundation's pioneering technical assistance program in Mexico, where he was research scientist in charge of wheat improvement. For the next 16 years, he worked to solve a series of wheat production problems that were limiting wheat cultivation in Mexico and to help train a whole generation of young Mexico scientists.

The work in Mexico not only had a profound impact on Borlaug's life and philosophy of agricultural research and development, but also on agricultural production, first in Mexico and later in many parts of the world.

It was on the research stations and farmers' fields of Mexico that Borlaug developed successive generations of wheat varieties with broad and stable disease resistance, broad adaptation to growing conditions across many degrees of latitude, and with exceedingly high yield potential. These wheats and improved crop management practices transformed agricultural production in Mexico during the 1940s and 1950s and later in Asia and Latin America, sparking what today is known as the "Green Revolution."

By the mid-1960s, Dr. Borlaug was taking his high-yielding "Mexican" wheats and crop management technology to Asia, first to Pakistan and India, and later to China, the Middle East, South America, North America, Australia, indeed anywhere that spring-habit wheats were grown. The impact has been spectacular. Over the past 40 years, wheat production in India has increased from 12 to 76 million metric tons; in Pakistan, from 4.5 to 21 million metric tons; and in the world, from 300 to 600 million metric tons.

The high-yielding wheat varieties that Norman Borlaug and his many scientific colleagues developed are today grown on more than 75 million hectares (187 million acres) throughout the world and may well be responsible for saving tens of millions of people from starvation.

Dr. Borlaug has always considered himself to be a teacher, as well as a scientist. Today, several thousand men and women agricultural scientists from more than 50 countries are proud to say they are Norman Borlaug's "students." Not only has he been a builder of individuals but he also has been a builder of institutions dedicated to the service of humankind.

With the establishment of the International Maize and Wheat Improvement Center (CIMMYT) in Mexico in 1966, Dr. Borlaug assumed leadership of the Wheat Program, a position he held until his "official" retirement in 1979, but where he has continued to serve as a senior consultant to this day. Since 1984, Dr. Borlaug has been the Distinguished Professor of International Agriculture at Texas A&M University, where he teaches one semester each year.

Since 1986, he has also been the President of the Sasakawa Africa Association and leader of the Sasakawa-Global 2000 agricultural program in sub-Saharan Africa—along with former U.S. President Jimmy Carter—which has worked with several million farmers in 15 countries of sub-Saharan Africa to increase food production.

Dr. Borlaug has been honored by scores of governments, universities, scientific associations, farmer groups, and civic associations. He holds 50 honorary doctorate degrees and belongs to the academies of science in 12 nations. He has served on two U.S. Presidential Commissions: on World Hunger (1978-79) and on Science and Technology (1990-92). He is also a member of the U.S. Wrestling Hall of Fame.

His directorships of the Population Crisis Committee and the Population Communications International reflect his long-term concern with the world population explosion and the pressure that this places on global natural resources, in the quest to feed a world that is now growing by nearly 100 million people per year.

In 1985, Dr. Borlaug was also the driving force behind the establishment of the World Food Prize, which is awarded annually in recognition of outstanding human achievements in the fields of food production and nutrition, and still serves as Chairman of its Council of Advisors.

Dr. Borlaug has served on the IFDC Board of Directors since 1994.

Lecture Series IFDC—LS-3
October 2003
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ISBN 0-88090-144-6