FERTILIZERS AND THE GREEN REVOLUTION: PAST CONTRIBUTIONS AND FUTURE CHALLENGES

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INTRODUCTION

I wish to thank Mr Hilmar Venter, and the organising committee of the Fertilizer Society of South Africa, for inviting me to participate in your 1997 annual meeting. I accepted this kind invitation because of the important role that the FSSA has played in the development of South African agriculture, and because of the very important role you must and will play in future years in the transformation of traditional small holder agriculture, not only in South Africa but indeed in many other parts of this continent.

During my 53 years of continuous involvement in food production programmes in developing nations, I have seen much progress in increasing yield and production of many crops, especially the cereals, in many food-deficit countries. Per capita cereal production has increased more rapidly than population, and the real prices of agricultural commodities have steadily declined for the benefit of consumers worldwide.

During the 1960s and early 1970s, the famine-plagued regions of the world were South and East Asia. I have had the pleasure and privilege of seeing these regions become essentially self-sufficient in basic foods, and have had the satisfaction of participating modestly in this effort. Currently, the most severe food-deficit-hunger region is Sub-Saharan Africa (SSA) where I doubt that I will live to see a Green Revolution, even though the ingredients that are required for such a revolution are already available.

DAWN OF MODERN AGRICULTURE

Science-based commercial agriculture is really a 20th century invention. Until the 19th century, crop improvement was in the hands of farmers. Potentially arable land was abundant. Whenever more food was required to meet the needs of a growing population more land was opened to cultivation. During the 19th century, development of new farm machinery expanded farm size and also made possible better seedbed preparation, soil moisture conservation and utilisation, and improved planting practices and weed control, resulting in modest increases in yield per hectare.

By the 1930s, much of the scientific knowledge needed for high-yield agricultural production was available in the United States, but its utilisation was delayed by the Great Economic Depression of the 1930s, which paralysed the world agricultural economy. It was not until World War II brought a great demand for food to support the Allied war effort that the new research findings began to be applied widely, first in the United States and later, after the war, in many other countries.

Using expanding knowledge in genetics and plant breeding, plant pathology, plant physiology, entomology, and cereal technology, scientists have been able to develop improved varieties of maize, wheat, rice and other food crops at an accelerated pace. Agronomists and soil scientists have developed improved crop production systems employing the use of these improved varieties, in combination with a 10-fold global increase in chemical fertilizer use, more effective control of weeds, diseases and insects, and a greater reliance on irrigation and/or improved moisture conservation techniques, which have allowed world food production to increase more rapidly than global population over the past three decades.

The advent of cheap and plentiful chemical fertilizers has been one of the great agricultural achievements of this Century. Rapid adoption began in the United States, Europe, and Japan after World War II. During the past two decades, chemical fertilizers - used in combination with high-yielding varieties and improved crop management practices - have permitted the densely populated nations of Asia to better feed their burgeoning populations and lower the real cost of food for everyone, but more importantly for the rural and urban poor. Even in China - which makes the best use of recycled organic matter, animal manure, and night soil in the world - huge investments have been made in chemical fertilizer facilities during the past 20 years and virtually all Chinese farmers now use chemical fertilizers. Chemical fertilizer production has increased from 6 000 nutrient tons in 1949 to over 25 million tons in 1995. Today, China is the world's largest producer, importer, and consumer of nitrogen fertilizers, and ranks second and third, respectively, in the consumption and production of phosphate fertilizers. China's investments in fertilizer production capacity have paid off handsomely. Today, this nation is practically self-sufficient in basic foods and has become the world's largest cereal producer. India lags behind China in cereal yields, despite the fact that high-yielding wheat and rice technologies were introduced earlier and expanded rapidly during the 1960s and 1970s. Nevertheless, India's attainment of self-sufficiency in cereals, achieved in 1975 and maintained up to the present, could not have been possible without heavy investments in fertilizers.

FEEDING THE WORLD: THE CHALLENGES AHEAD

In 1994 global food production of all types stood at 4,74 billion gross metric tons and 2,45 billion tons of edible dry matter (Table 1). Of this total, 99% was produced on the land; only about 1% came from the oceans and inland waters. Plant products constituted 93% 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 66% of the world food supply. Animal products, constituting 7% of the world's diet, also come indirectly from plants.

Had world food production been distributed evenly in 1994, it would have provided an adequate diet (2,350 calories, principally from grain) for 6,4 bilion

Table 1: World food production, 1994

Commodity	Production, million metric tons			
	Gross Tonnage	Edible Matter (1)	Dry Protein (1)	% Increase 1980-90 (2)
Cereals	**1 950**	**1 623**	**162**	**22**
Maize	570	501	52	19
Wheat	528	465	55	22
Rice	535	363	31	35
Barley	161	141	14	7
Sorghum/millet	87	78	7	-7
Roots & Tubers	**583**	**156**	**10**	**9**
Potato	265	58	6	3
Sweet potato	124	37	2	-7
Cassava	152	56	1	24
Legumes, oilseeds, oil nuts	**387**	**263**	**88**	**48**
Sugarcane & sugarbeet (3)	**133**	**133**	**0**	**21**
Vegetables & melons	**486**	**57**	**5**	**32**
Fruits	**388**	**53**	**2**	**28**
Animal products	**858**	**170**	**75**	**25**
Milk, meat, eggs	760	143	57	21
Fish	98	25	18	29
All Food	**4 743**	**2 456**	**343**	**24**

(1) At zero moisture content, excluding inedible hulls and shells.
(2) 1979-81 and 1989-91 averages used to calculate changes.
(3) Sugar content only.

Table 2: World population projections

Region	Population (millions)			% Increase
	1990	2000	2025	1990-2025
Low- and Middle Income Economies:				
Sub-Saharan Africa	495	668	1 229	148
East Asia & Pacific	1 577	1 818	2 276	44
South Asia	1 148	1 377	1 896	65
Europe	200	217	252	26
Middle East & N Africa	256	341	615	140
Latin America & Caribbean	433	515	699	61
Sub-total	4 146	4 981	7 032	70
Other Economies (1)	321	345	355	11
High-Income Economies	816	859	915	12
World	5 284	6 185	8 303	57

(1) This classification includes the former Soviet Union, Cuba, the Democratic People's Republic of Korea, for which inadequate and/or unreliable data is available.

people - about 800 million more than the actual population. However, had people in Third World countries attempted to obtain 30% of their calories from animal products, as in the USA, Canada, or EEC countries, a world population of only 2,6 billion people could have been sustained - less than half of the present world population.

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

During the 1990s, world population will grow by nearly one billion people and then again by another one billion people during the first decade of the 21st Century. A medium projection is for world population to reach 6,2 billion by the year 2000 and about 8,3 billion by 2025, before hopefully stabilising at about 11 billion toward the end of the

Table 3: Current and projected world cereal production and demand (million tons) and yield requirements

	Current Production	Projected Demand		Yield t/ha		
				Actual	Required	
	1990	2000	2025	1990	2000	2025
Wheat	600	740	1 200	2,4	2,8	4,4
Rice	520	640	1 030	2,4	3,1	5,3
Maize	480	620	1 070	3,7	4,1	5,8
Barley	180	220	350	2,3	2,7	4,1
Sorghum/millet	85	110	180	1,5	1,8	2,6
All Cereals	1 970	2 450	3 970	2,5	2,9	4,5

Source: FAO Production Yearbook and author's estimates

21st Century (Table 2).

As in the past, humankind will rely largely on plants - and especially the cereals - to supply virtually all of our increased food demand. Even if current per capita food consumption stays constant, population growth would require that world food production increase by 2,63 billion gross tons, or 57%, by 2025 as compared to 1990. However, if diets improve among the hungry poor - estimated to be at least 1 billion people - annual world food demand could increase by 100%. Using population growth rates shown above, and expected changes in per capita cereal demand, I have come up with the following cereal yield projections through the year 2025 (Table 3).

To meet the projected food demands, the average yield of all cereals must be increased by 80% between 1990 and the year 2025. Fortunately, there are still many improved agricultural technologies already available or well-advanced in the research pipeline, and only partially being exploited that can be employed in future years to raise crop yields. There are still large unexploited "yield gaps" in virtually all low-income, food-deficit developing countries as well as in the former Soviet Union and Eastern Europe. Yields can still be increased by 50-100% in many areas of Asia, Latin America, the former USSR, and Eastern Europe, and by 100-200% in much of sub-Saharan Africa.

THE REMAINING LAND FRONTIERS

Most of the opportunities for opening new agricultural land to cultivation have already been exploited (Table 4). This is certainly true for densely population Asia and Europe. Only in sub-Saharan Africa and South America do large unexploited tracts exist, and only **some** of this land should eventually come into agricultural production. But in populous Asia, home to half of the world's people, there is very little uncultivated land left to bring under the plow. Apparently in West Asia some 21 million ha are being cultivated than shouldn't be. Most likely, such lands are either too arid, or because of topography are so vulnerable to erosion that they should be removed from cultivation.

The last major land frontiers are the highly leached acid-soils areas of the Brazilian *cerrado* and *llanos* of Colombia and Venezuela, the acid soils areas of central and southern Africa and parts of Indonesia. These soil types were leached and made unproductive by Mother Nature in geologic time and now are being made productive by science and technology. Bringing these unexploited potentially arable lands into agricultural production poses formidable, but not insurmountable, challenges. However, it is my personal belief that the opening of the Brazilian *cerrado* and the other acid-soil areas mentioned above can contribute greatly to the adequacy in world food production for the next three decades.

In 1990 roughly 10 million hectares of rainfed crops were grown in the Brazilian *cerrado* with an average yield of 2 t/ha and a total production of 20 million tons (Table 5). The irrigated area is still relatively small, only 300 000 hectares, with an average yield of 3 t/ha and a total production of 900 000 tons. There are also 35 million hectares of improved pasture with an annual meat production of 1,7 million tons.

If the improved technology now available were widely and properly utilised in the areas of the *cerrado* now under cultivation it would be possible for farmers to attain 3,2 t/ha in rainfed crops and 64

Table 4: Potential cropland in the less developed countries (million ha)

	Africa	West Asia	S/SE Asia	East Asia	South America	Central America	Total
Potentially cultivatable	789	48	297	127	819	75	2 155
Presently cultivated	168	68	274	113	124	36	784
Uncultivated	621	0	23	14	695	39	1 392
% of region	79	0	8	11	85	52	Na
% of all regions	29	0	1	0,5	32	2	65

Source: Calculated from Buringh and Dudal (1987), Table 2.6, p.22.

Table 5: Production of cereals and meat in the Cerrado in 1990

Land Use	Area (10^6 ha)	Productivity (t/ha/year)	Production (10^6 T)
Crops (rainfed)	10,0	2,0	20,0
Crops (irrigated)	0,3	3,0	0,9
Meat (pasture)	35,0	0,05′	1,7
Total	45,3		22,6

Source: Prospectives for the Rational Use of the Brazilian Cerrado *for Food Production by Dr Jamil Macedo, CPAC, EMBRAPA, 1995.*

million tons of production. Moreover, irrigated area also can be increased to 5 million hectares, with an expected average yield 6 t/ha, for a total crop production of 30 million tons. Meat production could be more than doubled. Thus, in total, food production can be increased from the 22,6 million to 98 million tons, through widespread adoption of the improved technology already available (Table 6).

If international crop prices remain at the current high levels, I think we can expect a rapid diffusion of the improved *cerrado* technology developed by Brazilian researchers, progressive farmers, and agribusinesses. Still, there are serious problems in infrastructure. Transport costs to move these products to market, especially export markets, are high. To haul grain 1 500 km by truck still costs about US$ 40 per ton. Future developments of railroad and river transportation systems, along with continuing improvements in road systems, no doubt will greatly improve the economics of agricultural production of this region.

I believe that the opening to cultivation of additional vast tracts of the *cerrado* will play a central role in assuring the adequacy in world food supply for the next three decades while we also continue to use wise policies to stimulate production on the non-acid soil agricultural lands already in production in other parts of the world. Eventually, technology similar to what is being used in Brazil will move into the *llanos* in Colombia and Venezuela and into the countries of southern and central Africa and Southeast Asia and Indonesia where they have similar soil types. However, in the near-term in Africa, we must increase the food production on the land now under cultivation mostly in the non-acid soil types. It is on these soils where there is a better opportunity for more rapid pay off in the near-term if we can solve the current unavailability of fertilizers and improved seeds of high-yielding maize, sorghum, wheat and cassava varieties that fit the cropping systems, and also ensure that farmers practice adequate weed control.

WHAT CAN WE EXPECT FROM BIOTECHNOLOGY?

Over the past seven decades, conventional breeding programmes have produced a vast number of

Table 6: Potential food production if available technology is adopted on *Cerrado* area already in production

Land Use	Area (million ha)	Productivity (t/ha/year)	Production (million tonne)
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: Prospectives for the Rational Use of the Brazilian Cerrado *for Food Production by Dr Jamil Macedo, CPAC, EMBRAPA, 1995.*

progressively superior varieties and hybrids with higher grain yield, stability of harvests, and potential for profit. Surprisingly, however, there has been no major increase in the maximum genetic yield potential of the high-yielding semi-dwarf wheat varieties since those that served to launch the so-called Green Revolution of the 1960s and 1970s, even though there have been important improvements in resistance to diseases and insects, and in tolerance to a range of abiotic stresses, especially soil toxicities. But I must admit to being apprehensive about this and am convinced that we must find new and appropriate technology to raise potential genetic yield to higher levels, if we are to cope with the food production challenges before us.

I am now convinced that what began as a biotechnology bandwagon some 15 years ago has developed some invaluable new scientific methodologies and products, which need more active financial and organisational support to bring them to fruition in food and fiber production systems. So far, biotechnology has had the greatest impact in medicine and public health. Now, however, there are a number of fascinating biotechnological developments that are being employed in commercial agriculture. In animal biotechnology, we have *bovine somatotropin* (BST) that can increase milk production by 30% with half of this coming from increased production efficiency (increase in units of milk produced per unit of feed).

In plant biotechnology, genes from *Bacillus thuringiensus* (BT), are now available in commercial transgenic maize, potatoes, and cotton varieties. These new transgenic varieties will usher in a new era, whereby widespread effective insect control may be available on three of the world's most important crops, thus greatly reducing the use of insecticides.

The development of transgenic plants for the potential control of viral and fungal diseases is not nearly as far developed. Nevertheless, there are some very promising examples of specific virus coat genes in transgenic varieties of potatoes and rice that confer considerable protection. Other promising disease resistant genes are being incorporated into other transgenic crop species. Over the past five years, considerable progress has been made toward development of transgenic plants of cotton, maize, oilseed rape, soybeans, sugar beet, and wheat, with tolerance to a number of herbicides. This can lead to a reduction in herbicide use, by much more specific dosages and interventions.

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

The huge investments in biotechnology research made over the past 15 years have now begun to pay off commercially. This is most fortunate because, with limited uncultivated land suitable for production in most countries, most of the increases in food production over the next three decades must come from increasing yields on the land now under cultivation.

SUB-SAHARAN AGRICULTURE - THE GREATEST CHALLENGE WE FACE

Among all regions of the world over the past two decades, only in SSA has food output been growing slower than population. This has resulted in food insecurity for a large share of the population, with increasing levels of malnourishment, especially among children where some 29 million are suffering today. Social unrest, political instability, and massive migrations of destitute people, in a large part, is triggered by food insecurity, hunger, poverty and misery. If present trends continue, the number of malnourished children in SSA could climb to 53 million by 2020 (Rosegrant *et al*, 1995). Clearly, one of the major challenges facing the agricultural profession is to assure that this calamitous situation does not become a reality.

Between now and the year 2020, sub-Saharan Africa's (SSA) population will more than double to over 1,1 billion people. Investments by national governments and the international community have been insufficient to arrest poverty, assure food security, and reduce environmental degradation in this impoverished continent. Indeed, if present trends continue, food insecurity, malnutrition, and resource degradation will increase, and by 2020, it is conceivable that SSA could need to import between 50 to 70 million tonnes per year of foodstuffs (mainly cereal grains) to meet the demands of increased population (Dyson, 1995; GCA, 1996). Almost certainly, SSA will not have the economic resources to procure such huge volumes of food on a commercial basis nor will the international community be willing to provide the same as concessional sales or food aid.

In most regions of the world, increases in food supply over the past two decades have resulted mainly from raising yields. The only major exception is SSA where most of the growth in production has occurred due to expansion of the cultivated area. It is widely perceived that technology-based agriculture has by-passed SSA on a significant scale. Instead, where land is still plentiful, "slash and burn" shifting cultivation persists. Where population pressures have reduced the fallow period, a sedentary low-yield agriculture has arisen.

But no matter what the variations in the agricultural system, the most common limiting factor is that plant nutrients are limiting crop production. Traditional agriculture results in the mining of the soils for plant nutrients by crop removals, leaching, and soil erosion. Sanchez *et al* (1995) estimate that over the last 30 years, 100 million hectares of cropland in SSA have each lost 700 kg N, 100 kg P, and 450 kg K, primarily as crop harvest removals. These figures amount to a loss of plant nutrients in the range of 4,16 million tonnes annually. Other estimates put the losses even higher, at 8 million tonnes of nutrients each year (Bumb, 1995).

Traditional farming systems in SSA are responsible for the loss of 4 million ha of forest that are cleared annually, to substitute for the cropland that has become unproductive due to nutrient depletion. This practice is leading to disastrous environmental consequences, such as soil erosion, weed invasions, impoverished post-fire climax vegetative eco-systems, and loss of biodiversity (Borlaug and Dowswell, 1995). Clearly, the solution is not to expand food production horizontally to keep pace with population growth at the cost of environmental degradation, but rather to provide adequate soil nutrients by increasing fertilizer use, combined with organic inputs when available that build up organic matter in the soil, and complementary practices of using improved seeds and proper plant population, weed control, and other improved cultural practices.

It is estimated that around 50% of the annual global food harvest comes from the application of inorganic N fertilizer alone (Dyson, 1995). Expanded and judicious use of chemical fertilizers in SSA can play a critical role in preventing resource degradation that results from nutrient mining, and from the exploitation of fragile lands or the clearing of wildlife habitat-rich forests. At present, fertilizer consumption on food crops in SSA is the lowest in the world - probably no more than 5 kg per ha of nutrients, when fertilizer use on cash crops is subtracted from aggregate statistics.

Increased fertilizer use in SSA can create a win-win situation, by promoting more efficient crop production and reducing soil degradation. Chemical fertilizers should be at the core of soil fertility restoration strategies to raise crop productivity, although their use should be a part of integrated nutrient management systems in which organic fertilizer sources are included. However, organic sources of nutrients will be complementary to the use of inorganic fertilizers, and not the other way around.

It is also important to emphasize that sources of organic manure are limited in most of SSA countries. Even in Ethiopia, where livestock numbers are significant, manure is primary used as a cooking fuel and rarely to improve the fertility of the soil. Moreover, use of other organic sources, such as green manures, presupposes growing the manure crop at the expense of a food or cash crop. Finally, alley cropping and agro-forestry soil fertility maintenance approaches are knowledge-intensive nutrient-management systems that have met with only limited success, especially where poverty and hunger force farmers to employ desperate short-term survival strategies that take precedence over longer-term sustainability practices. Hence, efforts should be made to increase the efficient use of chemical fertilizers through sound policies and education, to attain economic growth and food security targets while reversing the damage to the resource base.

Since 1986, I have been involved with the Sasakawa-Global 2000 (SG 2000) agricultural program (Borlaug and Dowswell, 1995). Our mission is to contribute towards the attainment of food security through the adoption of productivity-enhancing technologies by small-scale farmers. The SG 2000 projects were conceived by the late

Ryoichi Sasakawa and have been funded since their inception by the Sasakawa Foundation, recently renamed as the Nippon Foundation, and are enthusiastically supported by former U S President Jimmy Carter. Projects are currently in operation in Benin, Burkina Faso, Ethiopia/Eritrea, Ghana, Guinea, Mali, Mozambique, northern Nigeria, Tanzania, Togo, and Uganda. Similar projects were also operated previously in Sudan and Zambia. SG 2000 conducts the majority of its program activities with, and through, national research and extension organisations. The core of the SG 2000 projects are dynamic field testing and demonstration programmes for the major food crops in which improved technology exists but for various reasons was not being adequately extended to farmers.

Working with national extension services during the past 11 years, more than 600 000 demonstration plots (0,25 to 0,5 ha) have been grown by small-scale farmers. Most of these plots (known by different acronyms depending on the country) have been concerned with demonstrating improved technologies in maize, wheat, sorghum, cassava, grain legumes, barley, potato, and, in the case of Ethiopia, teff (*Eragrostis teff*). Approximately two thirds of these plots have been planted to maize, either as a monocrop or in various intercropping patterns with cassava, grain legumes, or in several multiple cropping patterns with velvet bean (*Mucuna utilis*) and other green manure crops.

The improved technological packages being demonstrated on farms by frontline extension staff, with support from SG 2000, are based on data and improved cultivars developed by national and international research systems and are upgraded as new information and varieties become available. They include: (1) the use of the best available commercial varieties or hybrids, (2) improved agronomic practices that assure proper rates, dates and methods of planting, timely weed control, efficient use of available soil moisture, and when needed, crop protection chemicals, (3) proper application at moderate levels of appropriate fertilizers to restore plant nutrients to the soil, and (4) improvement of on-farm storage structures and methods for harvested grain, both to reduce postharvest losses and to extend the marketing season by safely holding stocks until prices are more favourable.

In virtually all of the SG 2000 project countries, demonstration plot yields have been two-to-three times higher than those obtained in the control plots or in traditional farmers' fields. Table 7 shows the yield performance in maize obtained by participating farmers in selected SG 2000 countries. Thousands of field days have been organised and attended by hundreds of thousands of farmers who are eager to learn about the success of their fellow farmers. A great deal of "copying" from farmer-to-

Table 7: Average maize yields in demonstration plots and farmers' fields in SG 2000 project countries, 1987-95

Country	Demonstration plots (t/ha)									Farmers' plots t/ha	Average increase over farmers plots (%)
	1987	1988	1989	1990	1991	1992	1993	1994	1995		
Ghana	2,8	4,0	3,3	3,2	4,2	2,8	3,3	3,0		1,3	150
Tanzania			5,2	5,2	4,9	3,9	2,4	4,8		1,4	208
Benin			2,8	2,4	2,9	3,4	3,2			1,0	187
Togo				2,5	3,5	3,8	3,3			1,2	187
Ethiopia							5,2	5,5	5,7	1,7	220

Source: SG 2000 files

Table 8: Fertilizer imports in Ethiopia (in tonnes), 1993-96

Year	DAP	Urea	N	P	Total NP	% Growth over previous year
1993	96 800	21 700	27 406	44 528	71 934	-24
1994	180 770	27 700	45 281	83 122	128 403	79
1995	201 500	43 700	56 372	92 690	149 062	16
1996	280 000	65 000	80 300	128 800	193 800	30

Source: National Fertilizer Import Authority 1996, Addis Ababa

farmer also is commonly observed. This demonstrates that the technology is not only easily understood and implemented, but also profitable. Another feature we have observed is that when a farmer innovates in one crop and understands the production principles, similar innovations in other crops will soon follow.

One of the exciting technological developments has been the introduction of quality protein maize (QPM), first in Ghana, and now in a number of other countries. QPM is one of the most unheralded research achievements in plant breeding of the past two decades. This nutritionally superior maize has much higher levels of lysine and tryptophan than traditional maize, and consequently has protein quality approaching that of skim milk. It has distinct nutritional advantages over normal protein quality maize, especially for monogastric animals, including humans. QPM is especially important as a food for mothers and as an infant weaning food. Today, QPM is commercially grown in only a handful of countries although I predict that its use is set to expand in at least another half dozen countries in the near future. South Africa's maize breeder, Dr Hans Gevers, is one of the pioneering leaders in QPM improvement. His hybrids are some of the best in the world. It is my fervent hope that the benefits of QPM will finally begin to be realised, and that South Africa will be at the forefront of diffusing this nutritionally superior maize, both as a livestock feed to reduce feeding costs, and especially as a superior human food, particularly for the poor who depend on maize "mealie" for a considerable portion of their calories.

If we were to single out one country that vividly demonstrates the potential for a Green Revolution in sub-Saharan Africa, Ethiopia would be the example for others to follow. As in other SSA countries, Ethiopian agriculture stagnated during the 1970s and 1980s, and the country was facing chronic difficulties to feed its ever-increasing population, which presently is estimated at around 55 million people. Annual food imports were close to one million tonnes over the last 10 years, mostly as food aid (mainly wheat). This bleak food-aid dependency has experienced a remarkable reversal over the past three years, due to the support provided by the Government of Ethiopia led by Prime Minister Meles Zenawi to put agriculture at the forefront of economic development.

As the result of this campaign, fertilizer imports into the country have increased from nearly 72 000 nutrient tonnes in 1993 to 193 800 nutrient tonnes in 1996 (Table 8). DAP constitutes the bulk of such imports. The usual recommended N:P nutrient ratio is 2:1, but in Ethiopia, actual consumption is more like 1:2, creating a nutrient ratio imbalance which needs to be corrected.

Driven by increased use of fertilizers and improved seed, better extension advice, and favourable rainfall over most of the country, cereal and pulse production in 1996 increased by more than 50 percent, or 4 million tonnes, above the 1994 harvests (Central Statistical Authority, 1996). The most spectacular gains thus far have been in maize, with a 31% increase in national yields over a three-year period and a 70% increase in production. Even in wheat, despite a stem rust epidemic that hit hard the most widely grown cultivar, Enkoy, substantial production gains have been made. With new stem rust-resistant bread wheat varieties now being multiplied, more rapid yield gains are expected in the coming years.

Policy planners have failed to fully understand the impact that the introduction of high-yielding food crop technologies can have on poverty reduction and on making agriculture the engine for economic development that it can, and must, become in sub-Saharan Africa. In most SSA countries, basic foods are too expensive rather than too cheap. They are too expensive because of the inefficient, low-yielding technologies that are being employed, which neither provide farmers with adequate incomes nor consumers with food at accessible prices. Farmers can increase their incomes through improvements in productivity and expanded production. More plentiful food supplies lead to lower real prices which, in effect, means increased income for all consumers, but with special benefit for the poor, since most of their income goes to acquire food.

Sub-Saharan Africa's extreme poverty, human diseases, eg, malaria, river blindness, trypanosomiasis, tuberculosis, guinea worm, aids, etc, poor soils, uncertain rainfall, increasing population pressures, changing ownership patterns for land and cattle, political and social turmoil, inadequacy of education system, shortages of trained agriculturalists, and weaknesses in research and technology delivery systems, lack of transportation and marketing infrastructures and credit systems, all make the task of agricultural development very difficult. Still, lessons from other parts of the world tell us what must be done to get agriculture moving. And as the Ethiopian case proves, with the right components and a strong political will, the process of agricultural modernization can be greatly accelerated.

Some agricultural professionals contend that the small-scale peasant food producers of Africa can be lifted out of poverty without the use of modern agricultural inputs, such as improved seed, fertilizer, and agricultural chemicals. They envision efficient crop production systems, based on organic fertilizers - which require little or no chemical fertilizer - rely on farmer-maintained indigenous varieties rather than those improved through science, only biological or mechanical control, but not chemical, of weeds, diseases, and pests, and only human power to carry out all farm operations. My 53 years of experience in low-income developing countries tells me that small-scale farmers are loath to adopt such "low-input, low-output" technologies since they tend to perpetuate human drudgery and the risk of hunger. This certainly has been our experience in Sasakawa-Global 2000, where farmers have overwhelmingly told us they want access to yield-increasing, drudgery-reducing technology, and have proven that they are able and enthusiastically willing to modernise their production.

STANDING UP TO THE ANTI-TECHNOLOGY CROWD

Science and technology are under growing attack by noisy, extremist environmentalists, mainly from the affluent nations, who claim that the consumer is being poisoned out of existence by the current high-yielding systems of agricultural production and recommend that we revert back to lower-yielding, so-called "sustainable" technologies. Certainly, both agriculturalists and environmentalists have a professional and moral obligation to warn the political, educational, and religious leaders of the world about the magnitude and difficulties of producing ever-greater quantities of foods to feed the unrelenting "population monster." But by the same token, we must face up to the fact that we cannot turn back the clock to the "good old days" before World War II, when world population stood at two billion people and when little chemical fertilizer and few crop protection chemicals were used.

Take the cases of the United States, India and China as examples (Figures 1 & 2). In 1940, when relatively little inorganic fertilizer was used, the production of the 17 most important food, feed and fiber crops in the USA totaled 252 million tons from 129 million hectares. Compare these statistics with 1990, when American farmers harvested approximately 600 million tons from only 119 million ha - 10 million ha less than 50 years before. If the United States attempted to produce the 1990 harvest with the technology that prevailed in 1940, it would have required cultivating an additional 188 million hectares of land of similar quality. This theoretically could have been achieved either by plowing up 73% of the nation's permanent pastures and rangelands, or by converting 61% of the forest and woodland area to cropland. In actuality, since many of these lands are of much lower productive potential than the land now in crops, it really would have been necessary to convert a much larger percentage of the pasture and rangelands or forests and woodlands to cropland. Had this been done, imagine the additional havoc from wind and water erosion, the obliteration of forests and extinction of wildlife species through destruction of their natural habitats, and the enormous reduction of outdoor recreation opportunities. Impressive savings in land use have also accrued to China and India through the application of modern technology to raise yields. Had the cereal yields of 1961 still prevailed in 1992, China would have needed to increase its cultivated cereal area by more than three fold and India by about two fold, to equal their 1992 harvests. Obviously, such a sur-

Fig. 1: USA total crop area spared by application of improved technology on 17 food, feed and fiber crops in period 1938-40 to 1988-90

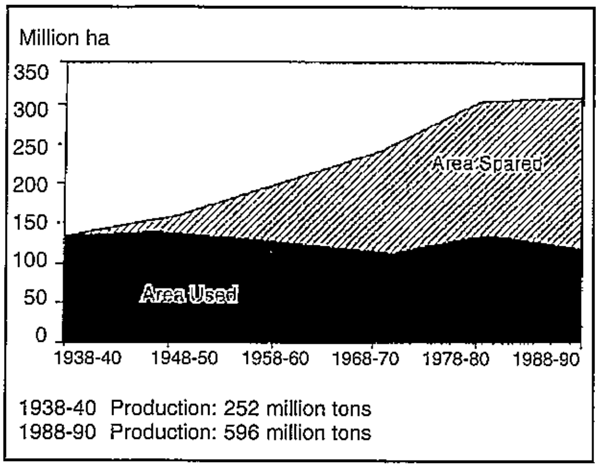
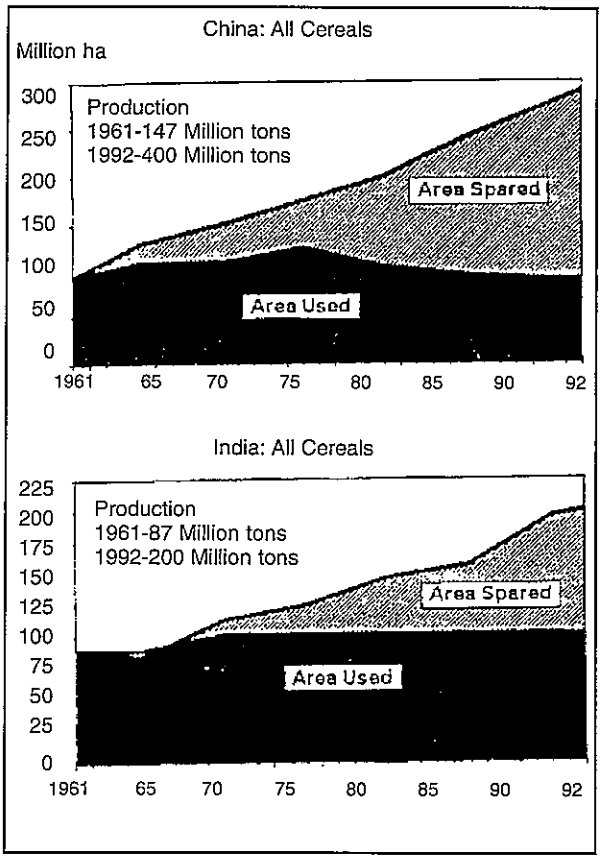


Fig. 2: The land that Chinese and Indian farmers spared through raising cereal yields*



** The upper curve shows the area that would have been needed to produce 1992 cereal production had 1961 yields still prevailed. The lower curve shows the area that was actually harvested.*

plus of agricultural land was not available.

I advocate using high-yield production technology on land best suited for agriculture so that the more fragile land can be felt undisturbed and/or used for other purposes, such as forestry, wildlife habitat, and recreation.

WHAT THE FERTILIZER INDUSTRY MUST DO

The South African fertilizer industry - indeed the global industry - have a crucial role to play in future years if food production is to keep ahead of population growth. Permit me to make several recommendations for action by this body - and at the global level from IFA.

(1) Mount much-expanded public information programmes to educate the urbanites about the role and critical importance of fertilizer in food production.

Much of the public confusion concerning the adverse effect of fertilizers and crop protection chemicals on food safety, dating back to Rachel Carson's book Silent Spring, published in 1962, could have been averted if business leaders and scientists had used the best scientific information available to counter the exaggerated accusations being put out by extremists in the environmental organisations. Instead, too many professionals who should know better have kept mum, thinking that, if ignored, the exaggerated claims being made by environmental extremists would fade away. They did not.

I believe the fertilizer industry, and the agricultural scientific community, have been especially neglectful. All too often they have permitted critics to refer in the same sentence to the toxicity of fertilizers and pesticides, as though they are of the same order of toxicity which, of course, they are not. Unless the chemical industry, including the fertilizer industry, stands its ground on the basis of scientific facts, it will see more stifling legislation and bureaucratic control over the use of agrochemicals. I am especially worried about the influence that extremist environmentalist groups have gained over foreign aid programmes. The worst of these elitist, anti-science groups advocate banning the supply of chemical fertilizers and crop production chemicals to developing countries. This would be disastrous.

FSSA and IFA must redouble their efforts to inform the press, media and general public about the critical need for fertilizer and the enormous benefits it has brought to humankind. The ignorance of the average citizen about fertilizer is both appalling and abominable.

(2) FSSA and IFA should police their own members and advise lawmakers on appropriate legislation to help avoid product adulteration and price gouging, which affects farmers, and to ensure that fertilizer is produced and used in environmentally responsible ways.

In many countries of sub-Saharan Africa, adulteration of products and mis-information about proper use procedures are rampant. There is a huge training job that needs to be done with fertilizer dealers to develop their technical understanding of the products they sell and their business ethics toward the farmer.

(3) FSSA and IFA should strive to ensure that efficient and effective input delivery systems are developed to serve small-scale African farmers.

One of the great hallmarks of developed market economies has been efficient agricultural research and technology delivery systems, in which private sector organisations play a major role in supplying information, inputs and services to farmers. In contrast, most Third World nations - and the former centrally planned communist block countries - tried to rely on publicly funded organisations to deliver improved technologies to farmers without much success. Plagued by many bureaucratic inefficiencies, public sector organisations have failed to delivery improved seed, fertilizers and other inputs effectively. These days there is disenchantment everywhere with "big government" and most developing country governments are looking for ways to get out of the business of supplying inputs, machinery and other services to farmers and turn these responsibilities over to the private sector. Thus, this is the time for the fertilizer (and seed) industry to be at the forefront of agricultural development in sub-Saharan Africa.

(4) FSSA and IFA should be much more aggressive in conducting the necessary research (economic, social, political) to advise policy makers (national and international) on the best policies to develop efficient fertilizer supply systems and application practices by farmers.

While too much subsidy of fertilizer by government clearly leads to waste and corruption - Nigeria being a glaring example - I believe that some level of subsidy, eg 10 to 30 percent, can be justified for an interim period, at least in the pre-Green Revolution low-income agrarian countries of sub-Saharan Africa, on the basis of infant industries, transportation constraints, social equity, and environmental protection criteria.

SUMMARY

Presently, population stands at 5,7 billion people and it is expected to reach around 8 billion by 2020, before hopefully stabilising at around 12 billion by the end of the 21st century. So far, agricultural research and production advances - and the efforts of cereal producers - have kept the rate of gain in grain production ahead of aggregate world population changes. Even though breakthroughs in science and technology will probably permit us to double and probably even triple global food production over current levels, I remain deeply concerned that humankind is being taken to the brink of disaster in hopes that a scientific miracle at the last moment will save the day. I believe there can be no lasting solution to the world food-hunger-poverty problem until a more reasonable balance is struck between food production and human population growth. Indeed, unless we address the question of "sustainable agriculture" from the perspective of "for how many" and "at what standard of living" this issue has little meaning. Thus, the efforts of those on the food-production front are, at best, a holding operation which can permit others on the demographic, educational, medical, family planning, and political fronts to launch an effective and humane attack to tame the population monster.

Most of the increases in food production needed over the next several generations must be achieved through yield increases on land now under cultivation. Moreover, these yield increases must be achieved through the application of technology already available or well-advanced in the research pipeline. Adoption of science-based high-yield agricultural technologies will not only lead to economic development but it will also do much to solve the serious environmental problems that come as a consequence of trying to cultivate lands that are not suited to crop production. Fortunately, many of the more-favoured agricultural lands currently under cultivation are still producing food at yield levels far below their potential.

Given present scientific know-how, the use of chemical fertilizers must be doubled at the very least in South Asia and Latin America, and quadrupled in sub-Saharan Africa, over the next 20 years. Clearly, the greatest need is in sub-Saharan Africa, which faces the horrifying prospect of only producing the food requirements for three quarters of its people by the year 2020, unless fertilizer use is greatly increased and combined with higher-yielding varieties and improved crop management practices. Surely, raising the average use of plant nutrients on food crops in sub-Saharan Africa from around 5 kg/ha to something like 40 kg/ha cannot be an environmental problem, but central to the environmental solution.

At the closure of the Rio Summit on the Environment in 1992, 425 members of the scientific and intellectual community presented to the Heads of State and Government what is now being called the Heidelberg Appeal. Since then, nearly 3 000 scientists at last count have signed. Permit me to quote the last paragraph of the Appeal:

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

For those of us on the food production front, let us all remember that world peace will not be built on empty stomachs. Deny farmers access to modern factors of production such as improved varieties, fertilizers and crop protection chemicals, and the world will be doomed - not from poisoning, as some say, but from starvation and social chaos.

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