PRESIDENTIAL ADDRESS

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Technology, Policy and Trade:
The Keys to Food Security and Environmental Protection

I am deeply honoured to deliver the 23rd Presidential Address to the International Association of Agricultural Economists. During my three years of office I have been privileged to visit over 40 countries on all continents, except Antarctica! This experience, involving both research and innumerable conversations (too numerous to cite individually) with agricultural economists, government officials and other well informed observers, forms the basis of my presentation.

I intend to address the problems of hunger and poverty in the world's rural areas in the light of the growing need and demand for food, linking that with farmers' potential to raise production to satisfactory levels without either substantially increased real prices or unacceptable environmental damage. I then turn to a highly stylized regional review of agricultural demand and supply potential, drawing inferences about the need for investment in agricultural research and necessary changes in both public policy and the global agricultural trading environment.

HUNGER AND POVERTY

Of the world's 5.8 billion people, an estimated 800 million suffer hunger. At the individual level, food insecurity is mainly caused by poverty. In no country do the rich go hungry except in times of war, natural disaster or politically imposed famine.

There are 1.3 billion people who subsist on an income of less that one United States dollar per day. The World Bank calculates that 80 per cent of the world's poor live in rural areas, where the bulk of the people earn their living from farming. Half of the poor live in less favoured areas. To understand the roots of the problems of poverty and hunger in rural areas, it is important to recognize that no country in the world has solved the problem of rural poverty by focusing exclusively on agriculture. Certainly, by raising farm productivity the lot of rural people can be improved, food availability can be increased and the real price of food reduced. But availability is not enough. It takes

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purchasing power to gain access to food needs above a family's own production. And there is not enough land per person in most rural areas for everyone who is trying to make a living from agriculture to grow enough to feed their family adequately and have sufficient left to sell to raise the family income above the poverty line.

The countries which have substantially reduced rural poverty have created off-farm employment opportunities, either within the rural communities or in distant cities. In the highest income countries today, the majority of farm families earn more than half of their income from non-farm sources. One or more members of the family work full-time or part-time off the farm. Some of these jobs are in agricultural input supply or in adding value to the raw products of the land. Many, however, are in cottage industries and other businesses completely unrelated to agriculture.

In many developing countries the only option for rural people to escape poverty is to move to distant cities. In 1990, there were four cities of over 10 million people in the world, and it is projected that by 2010 there will be 21 cities of this size, 13 of which will be in Asia. The diseconomies of supplying safe drinking water and social services and of removing garbage and sewage from cities of this size are overwhelming. While urbanization is a trend that is unlikely to be reversed, it could be slowed down if there were more attractive opportunities in rural areas. To do this will require much larger investments in roads, communications, education, health care and putting the necessary preconditions in place for employment and enterprise growth. These investments in infrastructure and human capital are also important for successful agricultural development.

The world's population continues to grow rapidly, though the growth rate is falling faster than many analysts expected. Each year the United Nations' median projection of the world population is revised downwards. Much that is written about the ability of the world's farmers to feed this population adequately and without environmental damage focuses on the number of mouths to be fed. Certainly, population growth creates additional need for food, but whether that need is translated into effective demand depends on purchasing power.

While the rise in numbers attracts most of the media attention, what has been much less noted is the broad-based economic growth which has been empowering millions of poor people with the means to upgrade the quality of their diets. As families gain more income, the first thing they do is modify their diet, usually by including more fruits, vegetables, animal protein, edible oils and sweets. This income effect accounts for more of the recent growth in global demand for food than population growth. While there are hundreds of millions of people in the world who have been left behind by this economic growth, many millions more are participating, particularly those living in urban areas. Much of the growth is export-led and is in East and Southeast Asia. Much also is associated with privatization and moves to a market economy.

The combined effects of population and income growth are expected to double global food consumption in the next 30 years. This brings us to the question of aggregate global food security. At the national level, food security is a problem of availability. We ask whether a country's farmers can satisfy its

food demand at competitive prices. Each country should use its arable land and agricultural production potential to the fullest extent that it can efficiently or without wasting resources, that is at a marginal rate of transformation which is lower in domestic production than in trade. It is important to recognize that investments in agricultural research can often modify the domestic marginal rate of transformation to create a comparative advantage in agriculture where it did not exist previously. If a country cannot efficiently produce its own food, it must either export other products to earn the foreign exchange to import its needs or hope that a dependable supply of food aid is available.

Food security at the global level is a question of whether the world's farm and food system can provide twice or even three times as much food as today, at no higher real cost, and do it in a manner that does not destroy the environment. There are only three ways to increase global availability: increase the land area planted, increase yield per hectare and reduce post-harvest losses. If we were to double food production by doubling the amount of land under cultivation, it would create massive environmental damage. It could only be done with large-scale destruction of forests and, with them, wildlife habitat and biodiversity. This would also reduce the carbon sink and destroy the homes of indigenous peoples.

This paper examines how much more fertile, well-watered, unforested, non-erodible land is available and where, and then draws inferences for research, public policy and international trade in ensuring food security without environmental damage. In the next section of the paper we will take a highly stylized tour of the continents addressing these questions.

ASIA

Asia has a much larger fraction of the world's population than of its arable land. Many parts have made significant investments in agricultural research and in education. A number of countries of East and Southeast Asia have been experiencing very fast economic growth with rapid creation of non-agricultural employment, often widely dispersed through the countryside. As per capita incomes rose from a low to a middle level, diets rapidly diversified. Despite significant growth in agricultural productivity, food consumption quickly exceeded internal food production capacity, and agricultural imports grew rapidly, particularly for feed grains and protein meals for livestock and poultry. As incomes have risen, rice consumption has fallen and that of wheat has grown.

The land–labour ratio in most of these countries is very low. Some of the highest income countries of East Asia introduced quite generous price supports and protectionist import policies for their most important traditional products. However, even with these policies, they could not provide parity of income to their farmers from their small landholdings. As a result, large off-farm migration has occurred, and part-time farming has become a common means of supplementing farm income.

With 1.2 billion people, China has 22 per cent of the world's population, but it has only 9 per cent of the arable land. Though population is expanding slowly, the economic growth rate of around 10 per cent per year is causing

diets to alter rapidly, with large increases in poultry and pork consumption in particular. China experienced very rapid growth in agricultural output during the 1980s, following its economic reforms, but its future ability to feed itself has become an issue of great media attention and numerous academic conferences, including an IAAE interconference symposium last year. Until recently, there was significant doubt about how much productivity growth potential still existed. However, the recent announcement by the State Statistical Bureau that the land area under cultivation had been significantly underestimated means that crop yields per hectare are lower than previously thought. With larger investments in agricultural research and in technology transfer, it should be possible to raise yields considerably.

Over the last 20 years, China's public policy has varied, in the amount of support it has given to agriculture. The recent 'Grain Bag' policy, which encourages provincial self-sufficiency, has been a step backwards. In addition, the inadequate rural transport infrastructure reduces the ability of the international market to function efficiently. Some attention is being given to the need to increase the production of high-value plant and animal products in place of cereals, with the objective of not only supplying domestic demand, but also generating export revenue that could pay for imports of even more grain than could be grown on the same land. Consistent with this, the government of China has reduced its cereals self-sufficiency goal from 100 per cent to 92 per cent. China is likely to become the world's largest importer of maize and soybeans.

While China has received most of the recent media attention, we should also pay attention to India. Some demographers now project that by the middle of the next century India will have 1.5 billion people, and China, 1.4 billion. India has made large investments in agricultural research. The 'green revolution', which began in the late 1960s, satisfied the growth in food demand for at least one generation. It is important to remember that India has 250 million middle-class consumers, but also half a billion very low-income people. While India has been slow to abandon the socialist model and let market forces work, economic growth is starting to accelerate. If this becomes broad-based, diets are likely to change, and India could also place greater demands on the world food system. Consumption of dairy products is already large and with higher incomes Indian consumers are likely to eat considerably more poultry and sheep and goat meat.

Having so much more of the world's population than arable land, Asia is likely to become an even larger net food-importing region as per capita incomes rise, drawing much larger agricultural exports from other regions of the world.

AFRICA

Africa has experienced rapid population growth and slow economic advance. It is the one continent with declining per capita food production, which has been going on for three decades. Africa has the geologically oldest exposed land surface in the world and heavy weathering of its soils has left them with weak

structure and very low nutrient content. Many regions have low annual rainfall with quite high variance, while some are prone to desertification. It is the continent with the greatest natural limitations to high-productivity agriculture. While there is a modest amount of additional land that could be brought into use, especially in the southern cone, much of this is subject to these same climatic and soil quality constraints.

There is a smaller cumulative stock of agricultural research results available in Africa than in other continents. This reflects an underinvestment by national governments and by the international system. Because the food staples are crops not widely grown in other parts of the world (for example, millet, sorghum, yams and sweet potatoes), there is also much less international research upon which to draw than for wheat, rice or maize. Nevertheless, the available research demonstrates that high yields are attainable in many regions of Africa with improved varieties, better soil management and applications of chemical fertilizers.

Many countries have had a pronounced anti-rural or anti-agricultural bias in their public infrastructure investments and agricultural price policies, enforcing price ceilings and accepting dumped food aid to keep food cheap in the cities. This, in turn, depresses farm prices. As a result of the terrible condition of most rural roads, the cost of transport is extremely high. This further depresses the farm-level prices of commodities and increases the cost of fertilizer and other purchased inputs. Such price-distorting effects have often been further accentuated by inefficient parastatal marketing monopolies. As a result, it is simply not profitable for farmers to adopt the improved technologies which are available to many parts of Africa.

Diffusion of improved technologies is impeded also by several other factors. The agricultural extension service is often weak and fails to recognize that working with the 70 per cent of African farmers who are women may require a different approach than working with men. The private sector serving agriculture is often not well developed because of inadequacies in the legal code or because of unfair competition from inefficient, but subsidized, public companies. Moreover, credit is often not readily available.

Agricultural productivity could be much higher than it is now in Africa, and somewhat more land could be brought into production without causing environmental damage. The continent could also produce much more of its food supply.

The anti-rural bias of many African governments is also reflected in the low priority which they place on agricultural and rural development projects when approaching foreign aid donors and the international development banks. There are often more resources available to Africa for agricultural and rural development than are taken up.

If and when faster economic growth occurs, it will cause food consumption to grow even faster. Therefore, even with some agricultural successes, I expect Africa to continue to be a net food importer from the rest of the world, on both a commercial and food aid basis, well into the 21st century.

WESTERN EUROPE

Western Europe is a mature, highly protected, high-income market, with limited expected growth in food consumption. Its high-income consumers are very quality conscious and are placing increasing demands upon their food system for organic foods and for labelling products for content and for indications of the processes used to grow the raw agricultural outputs involved.

Large investments in agricultural research and relatively high price supports have led to very high agricultural productivity levels by international standards. The European Union's price policy substantially stabilized the internal prices of most products, insulating farmers from international price shocks. Agricultural production has grown much faster than internal consumption over the past two decades, with substantial quantities being exported with the assistance of subsidies to offset the high internal support prices.

Government stocks have accumulated at various times as a result of price support operations and have often been donated as food aid to poor countries. A land set-aside programme and marketing quotas have been used to constrain overproduction stimulated by the high price supports. In response to both financial and political pressures, the EU's price support levels have been reduced significantly in recent years. Furthermore, in the Uruguay Round GATT agreement, the EU agreed to reduce its subsidies to agricultural exports.

Western Europe has had some of the most intensive crop and livestock production in the world in terms of livestock feeding rates and heavy fertilizer and agricultural chemical applications. This has led to adverse environmental consequences, especially in surface and ground water where nitrates and pesticide residues have accumulated. As a result, environmental activists have sought and achieved government regulations to reduce the adverse consequences of intensive farming.

In addition to environmental measures, a number of Western European countries also impose animal welfare regulations and other production process rules which prevent their farmers from adopting cheaper technologies available elsewhere in the world. Other regulations restrict the ability of European agricultural scientists to use certain powerful basic research tools to develop productivity-enhancing and cost-reducing technologies, or prevent European farmers from adopting such technologies developed in other countries. Biotechnology is a prime case in point. Such regulations tend to increase the unit cost of agricultural production and reduce the competitive position of European farmers. Their competitiveness has been further reduced as the value of price supports and marketing quotas has been capitalized into farm asset values, thereby raising the capital cost of farming in Europe relative to other countries.

An unanticipated consequence of the EU price supports was a loss in the domestic market for cereals in livestock rations. Imports of several cereal substitutes, in particular manioc, have been admitted free of tariffs. As a result, the relatively more highly priced cereals grown in Europe dropped out of least-cost ration formulations, to be replaced by manioc imported from Southeast Asia and by other cereal substitutes. This further increased the fraction of the EU's cereal production to be exported. As cereal price supports have been

reduced in the last few years, more locally grown grain is going back into least-cost rations, reducing the quantity available for export.

As price supports have fallen and environmental regulations have been imposed, the intensity of agricultural input use has been reduced in Western Europe, and the volume of agricultural products available for export has fallen. As EU-grown cereals once again replace cereal substitutes in rations and as export subsidies are further reduced, this will limit agricultural export prospects. Therefore, despite the likely growth in world agricultural import demand in the next century, I expect that Western Europe's agricultural exports will be no larger, and will probably be smaller, than recently.

CENTRAL AND EASTERN EUROPE

Agriculture in Central and Eastern Europe underperformed relative to its potential under central planning during the socialist period. To appreciate the productive potential of this region, one has only to recall that the Ukraine, which has some of the world's most fertile soil, was the largest wheat-exporting country as recently as 1930. The former Soviet Union was a major cereals importer during the 1970s and 1980s.

During the socialist period, food consumption levels were quite high relative to other countries because of food price controls and large consumer subsidies for food. Processing was generally done by large-scale state monopolies, which paid little attention to consumer service or quality control.

Agricultural productivity levels have been low by international standards. This reflects inadequate economic incentives, weak applied research and technology transfer, and unreliable agricultural input supply systems. Production units were often extremely large, but with inadequate information-processing capacity and incentives available to manage effectively such large-scale units. Post-harvest losses were very large, with estimates as high as 40 per cent lost between the field and the consumer.

The agricultural sector of the former Soviet Union consistently performed weakly relative to its potential. While some observers point to the constraints imposed by its northern climate, such disadvantages have not prevented Canada, with a similar climate, having consistently been a major agricultural exporter. Basic agricultural science in the former Soviet Union was well respected by international standards but, by contrast, applied research and technology transfer was weak. For example, conversion rates of feed into meat were very low because rations were not balanced with enough protein. There needs to be a much stronger two-way flow of information between production agriculture and agricultural researchers, with stronger incentives to study real world problems of importance to the farm sector. Since the economic reforms, public investment in agricultural research has declined, and many formerly prestigious institutes have fallen on hard times.

Since the beginning of economic reforms in the former Soviet Union, per capita income has declined and the previously large food subsidies have been eliminated. As a result, food consumption has dropped. A reduction in agricultural production subsidies has resulted in output declining even more, especially

in animal agriculture. The previously large periodic bulk commodity imports, particularly of feed, vanished. With the liberalization of imports, a number of high-value commodities, including meats and processed foods, are being imported. These could be produced in the region, but the consumers with purchasing power to buy such goods are dissatisfied with the domestically supplied items owing to lack of attention to customer service and quality control.

As the economies of Central and Eastern Europe have moved towards a market system, privatization of agriculture has begun, moving at varying speed. In many cases, property rights are still ill-defined, and not easily registered, protected, transferred or pledged as collateral against loans. Private input markets and sources of production credit have been slow to evolve. Rural roads and other marketing infrastructure, including bulk and refrigerated storage, have not been improved fast enough. Public monopolies have often replaced state monopolies, with no improvement in customer service or quality control. The old state-supported basic research system has collapsed for want to resources and has not been replaced by an effective applied research and technology transfer system. Public policy continues to reflect an anti-agricultural bias, with farm product prices depressed well below world market levels and farm input prices held well above world values.

Once the transition to a market economy is completed and these problems are addressed, there is no reason why the countries of Central and Eastern Europe cannot supply more of their internal consumption and be large exporters of a number of crop and animal products. The northern countries of Central Europe are well poised to do this soon, but those of the former Soviet Union and the southern countries of Central Europe appear to be a number of years away from achieving their potential. Nevertheless, as we contemplate the capacity of the world's farmers to produce twice or three times as much food as today at no higher price and without environmental damage, this region will have an important role to play.

SOUTH AMERICA

South America is the region of the world with the largest area of arable land available to be brought into agricultural production without causing deforestation or other environmental damage. While the destruction of the Amazon rain forests receives a great deal of media coverage, there is abundant non-erodible unforested land that can be brought into agricultural production in regions south of the Amazon. South America is a region of abundant land area relative to its population, and it has some of the world's most fertile soil in its southern cone. While it is an historically important agricultural exporting region, its performance has not matched its potential. Indeed, it has not done so for over 60 years. Many countries have had a strong anti-agricultural bias in their public policies, often failing to invest enough in rural services and infrastructure, and imposing heavy taxes on agricultural exports. Public policy so depressed returns in agriculture that it remained a very extensive industry with very low productivity per hectare. It was not profitable to adopt higher yielding varieties and to apply much fertilizer.

Exports have often been further taxed implicitly by overvaluation of exchange rates, and bouts of hyperinflation have caused flight of capital into agricultural land. Until recently, many countries followed import-substituting industrialization development strategies which created inefficient, but highly protected, non-agricultural sectors, which further increased farmers' costs. Recently, this situation has been changing rapidly in many Latin American countries. Economic reforms have liberalized their economics and an export-led growth strategy has been adopted. Agricultural export taxes have been cut, and several outstanding agricultural export success stories have occurred in the last 20 years, including soybeans and frozen concentrated orange juice in Brazil, fruits and wines in Chile, and cut flowers in Colombia.

Brazil, in particular, has made a major commitment to public investments in agricultural research. As a result, the huge *campo cerrado* region in the central west part of Brazil has been converted from an unproductive region of scrub vegetation to a highly productive producer of soybeans. This is but one example of how investments in agricultural research in the region are breaking natural bottlenecks to expansion of agricultural production to meet the growing world market demand.

It is important to recognize that the distribution of income and wealth is more skewed in South America than in other regions of the world. If an economic development strategy is adopted which successfully increases the incomes of the millions of poor people, there will be a large increase in demand for agricultural products within the continent, with a larger proportion of output being consumed internally rather than being exported. Nevertheless, the region is expected to supply a much larger volume of agricultural exports to satisfy the growing import demand in Asia and other areas in the 21st century.

OCEANIA

Oceania, which is dominated by Australia and New Zealand, has historically been a strong agricultural exporter, and is expected to continue to be in the future. In these mature, high-income markets, internal demand for agricultural products is growing slowly. Both the major countries have traditionally afforded their agriculture low levels of government assistance and New Zealand has now completely eliminated agricultural support. Historically, there has been strong investment in agricultural research, often paid for by taxes that farmers have imposed upon themselves. With high productivity levels, agricultural export potential is limited mainly by size and climatic constraints, in particular, low rainfall in much of Australia.

Both countries have significantly repositioned their agricultural sectors in recent years to take advantage of the rich and growing markets to the north, in Asia. Australia has experienced a large increase in dairy and cattle production, and New Zealand in dairy products and fruits. Both have shifted the balance of their exports from bulk commodities to higher-value agricultural exports whose demand is growing in the more affluent Asian markets. They will continue to be major agricultural exporters, but with limited expansion potential.

NORTH AMERICA

North America has a mature, high-income, slowly growing market for agricultural output. As a result, the region, which has invested large sums in agricultural research and is blessed with large expanses of fertile, well-watered soils and a relatively low-cost transport system, has become the largest agricultural exporter in the world. However, as in the other regions described, agriculture is also undergoing significant changes.

Canada has a large land area and sparse population. While agriculture might be expected to be constrained by its northerly climate, large investments in agricultural research and rural infrastructure made it possible for Canada to become a major agricultural exporter. Farming has also benefited from substantial government assistance. Prairie grain producers benefited from large subsidies to rail transport to ocean ports for almost a century, until two years ago, when the subsidy was eliminated. As a result, prairie agriculture is rapidly repositioning itself and has substantially increased the production of oilseeds, particularly canola, and fed livestock, particularly cattle and hogs, relative to wheat. The balance of exports has shifted towards higher-value products, particularly meats.

Canada has a highly protected segment of its agriculture which has been supported by production quotas, particularly dairy and poultry. The capitalized value of the quotas has raised the cost of production, and these sectors have stagnated technologically. As a result, they are not internationally competitive and are unable to expand to take advantage of growing international market opportunities. There are large political constraints to change in policies, though Canada has significantly reduced the assistance it provides to its agriculture and the sectors not subject to supply controls have responded quickly to greater world market opportunities, particularly in higher value products. We can expect Canada to be an even larger exporter of both bulk commodities and higher valued items in the future.

About half of the United States agriculture, in particular field crops and dairy, received significant levels of government support for more than 60 years, while the rest of American agriculture, including horticultural crops and the remainder of animal agriculture, was basically operating on free market principles. In 1996, Congress made the largest changes in agricultural policy since support began in 1933. Most subsidies linked to the volume of agricultural production were eliminated. This effectively removed the government from the business of stock holding. Set-asides associated with price supports were eliminated, except for long-term setting aside of erodible or environmentally fragile land in the Conservation Reserve Programme. Target prices and deficiency payments were eliminated. Even price supports to the dairy sector, which previously had been guarded by one of the most politically powerful lobbies, were cut. The effect of all of these changes was to move most of the previously protected parts of American agriculture to free market conditions. The changes have significantly increased farmers' planting flexibility and responsiveness to world market demand. While government programmes formerly provided substantial protection against risk, American farmers are well served by market institutions which permit them to manage risk at reasonable cost, in particular by means of well-developed futures markets.

While many parts of the United States are blessed with fertile soils and favourable climatic conditions, public and private investments in agricultural research and transport infrastructure account for significant parts of the international competitiveness of agriculture. In the last 20 years, public investments in agricultural research have declined in real terms, but there has been a large increase in private-sector efforts. In part, this reflects improvements in intellectual property protection which ensure that the private sector can reap the returns on its spending on research. Developments are focused particularly in biotechnology and in electronic sensors, information processing and geopositioning systems.

Another major recent innovation has been low-till agriculture or conversation tillage, which reduces labour and energy costs, conserves moisture and improves soil conservation. Applications of the electronic technologies in so-called 'precision farming' are starting to expand, and we are poised at the beginning of the biotechnology revolution in production agriculture. These technological changes are expected to increase productivity substantially and reduce unit costs of production, while having positive environmental effects as well. They should make it possible for the United States to further expand agricultural output and exports.

Several sectors of American agriculture are undergoing rapid structural change. While the transformation of the poultry industry lasted several decades, the corresponding process has occurred almost overnight in the pig industry and is occurring in parts of the dairy sector, particularly in the south-west. By bringing together state-of-the-art genetics, nutrition and disease control methods, with electronic sensors and information processing capacity, it has become possible to manage large-scale production units at high productivity and low unit cost. While animal waste disposal from large production units is a significant environmental challenge, there appears to be a comparative advantage in locating such units in wide open spaces away from concentrations of population.

In 1981, 90 per cent of agricultural exports were raw, bulk commodities. Today over half are high-value products like meats, fruits, vegetables, nuts and wine. I anticipate that in the future the United States will export a larger fraction of its maize and soybeans in the forms of meat and other animal products, including dairy products. It will also export large quantities of high-value products from the horticultural sector, but it will also continue to be a large exporter of food and feed grain and oilseeds.

GENERAL OBSERVATIONS

Simultaneously with rapidly growing demand for food due to population and income growth, the structure of demand is changing all over the world. In low-income countries, demand for meat and other animal products, fruits, vegetables, edible oils and sweets is expanding. In a number of high-income countries, consumers are wanting much more processing, packaging, food safety, nutrition, labelling of production processes and specialized products, like organic and vegetarian foods. This is requiring the marketing system to be able to

preserve the identity of smaller lots of more differentiated products as they move through national and international markets. In any case, it is important to think of agriculture as part of a total food system, which exists to satisfy consumer demands.

A bifurcation of the size distribution of farms is occurring all over the world. We may soon reach the point where 20 per cent of the world's farms produce 80 per cent of the output. The high-producing segment will have high land–labour ratios and high capital–labour ratios. In fact, agriculture may be more capital-intensive than the rest of the economy. Such farms are generally in the more favourable agroclimatic zones. They use state-of-the-art production technologies and highly sophisticated management, including financial management, risk management and marketing strategies. Their unit cost of production is very low, and they earn their investors a competitive rate of return. These farms have the potential to increase output sharply at low unit cost of production.

The situation is very different for the 80 per cent of the world's farmers who collectively grow only 20 per cent of the output. They tend to be concentrated in areas of high population density, often in the less favourable agroclimatic zones. Many are located in hilly or mountainous areas. Typically, there is little physical capital in agriculture and little credit available. In many countries the governments have invested little in education, health or other rural social services. These areas are generally characterized by widespread poverty, with few non-agricultural income sources. There is simply not enough land per person available for everyone to grow enough for their own families' consumption and have enough more left to sell to provide a family income that exceeds the poverty level. Many of these regions can increase their food production. Increasing agricultural productivity can help, as can shifting their mix of products to high value per hectare crop and animal enterprises. However, without creating part- or full-time employment opportunities off the farm, difficult though that is, there is little hope of solving the problem of rural poverty and hunger in such areas. If their poverty is reduced, these rural areas may increase their food consumption at an even faster rate, reducing their food self-sufficiency. The transport and communications infrastructure necessary for successful rural economic development is also important to link local agricultural and food markets to national and international commerce.

Rapid changes are under way in national agricultural policies in many parts of the world. There is a widespread move to place greater reliance on market forces and to reduce the role of government. Many high-income countries are cutting the subsidies they have provided to their farmers, especially those that have been linked to the volume of production. They are making direct payments to farmers instead of distorting market prices. These measures are reducing inefficient production in high-cost producing areas and dumping of the resulting surpluses onto the world market. The availability of food aid is also falling. A number of low-income countries have reduced their government intervention in agriculture and permitted domestic agricultural prices to rise closer to world market levels. However, much more progress is needed to eliminate the anti-agricultural bias in their public policies.

In many low-income countries and economies in transition to a market economy, property rights are inadequately defined and protected. Many also

lack an adequate commercial code and contract dispute settlement procedure for a well functioning private sector to emerge, create employment and contribute to agricultural and economic development.

Agricultural markets are becoming global in extent as the fraction of the world's agricultural output that moves through international markets grows. This has been facilitated by a tendency towards a freer and more open international trading environment. It was further advanced by the recent agreement under the Uruguay Round of multilateral trade negotiations under the GATT. This agreement officially acknowledged, for the first time, that domestic agricultural aid linked to the volume of production can distort trade, and it reduced and bound domestic subsidies. The agreement mandated a reduction in the volume and value of agricultural export subsidies and guaranteed a minimum access for imports to every market. The agreement also established that good scientific reasons must exist before sanitary and phytosanitary barriers can be imposed on imports.

With few exceptions, the agreement required that non-tariff barriers to imports be converted to tariffs, often referred to as 'tariffication'. This was important because quotas and other non-tariff barriers had effectively cut the link between internal and world market price in many countries. As a result, world prices were much more volatile in response to supply shocks than they would have been if all countries shared in the adjustment to the shocks. Tariffication fell short of its expectations in stabilizing world market prices, however, because the tariffs were set at prohibitively high levels under so-called 'tariff rate quotas'.

To achieve greater world market price stability, these tariff rates will have to be cut substantially and the quotas increased. The existence of undue international price instability makes countries less willing to rely on the world market for their food security. However, with modern global telecommunications and transport infrastructure, there is no reason why the world market should not be able to ensure national food security. For this to occur, countries have to be confident that they can be assured access to supply in any year, and that they can sell the goods in which they have a comparative advantage in the world market.

Today there is great public concern about protecting the quality of the environment. This often manifests itself in regulations which restrict agricultural production practices, particularly in the application of chemicals. It is unfortunate that sweeping generalizations are made concerning the environmental effects of chemical fertilizers and pesticides. Some are harmful, with long persistence in the environment and high mammalian and avian toxicity, yet many others are quite safe. Much of the modern chemistry is applied in small doses and quickly degrades into harmless by-products after it serves its purpose. Biological controls and integrated pest management are also important tools in controlling pests, but are not likely to suffice. Biotechnology, which some environmental activists also criticize, has great potential, not only to raise productivity, but also to breed in resistance to diseases, insects and other pests, reducing the need for chemical controls.

The greatest environmental danger, however, will occur if the best that science has to offer is not brought to bear on increasing productivity substantially from present levels. If we should attempt to double or triple agricultural

production by doubling or tripling the area planted, this would require massive destruction of forests and, with them, wildlife habitat and biodiversity, and it would reduce the carbon sequestration capacity of the forests. The only acceptable alternative is to increase productivity on unforested fertile non-erodible soils and in animal production systems, and to reduce post-harvest losses.

Another important environmental problem of agriculture today is related to disposal of animal wastes without causing nitrate accumulation in the groundwater. A further constraint on production is likely to be the adequacy of water. Supply of water to farmers is often priced at zero. As a result, a great deal is wasted and there is little incentive to adopt water-saving technologies. Greater incentives for more efficient use will have to come in the 21st century, or water shortage will become a severe constraint on world food supply.

CONCLUSIONS

(1) There is a limited amount of additional fertile, well-watered, non-erodible, unforested land available in the world that can be brought into agricultural production at low cost. This tends to be in North and South America and southern Africa. There is somewhat more land that can be brought into production with significant investment in reclamation or irrigation.

(2) A great deal of much higher-productivity technology is available in the world than is at present in use. For example, there is widespread application of fertilizer with the wrong nitrogen–phosphorous–potash balance and frequent use of rations for poultry and livestock with a defective energy–protein mix. As a result, the productivity of input use is much below potential. In some cases, the technology transfer system is deficient, and farmers do not know better; in others, the marketing system, especially when it is in the public sector, does not make the proper inputs available. In many countries, public policy depresses output prices and increases input prices, so that it is not profitable to adopt higher-yielding technologies. Investments in transport infrastructure are essential to reduce the costs of input supply and product marketing. These observations are particularly appropriate for Africa and Eastern Europe.

(3) We are living in the golden ages of the biological sciences and of information processing. There are numerous powerful research tools available to agricultural scientists to develop environmentally benign production technologies. However, just as these powerful tools were becoming available, the public sector often reduced its investments in agricultural research at both the national and international levels. The private sector has increased its spending, but not by as much as the public-sector cuts. In several countries, government regulations have restricted the ability of the private sector to apply some of the powerful new research tools, such as biotechnology. Many governments provide inadequate intellectual property protection, or so increase the cost of obtaining approval to sell the products of their research that the cost becomes prohibitive. Moreover, the private sector will not invest in minor products, or in regional staples of poor countries where there is a limited commercial market for the

products of research. Overall, there is substantial lack of investment in agricultural research relative to what is needed to raise productivity on fertile, non-erodible soils. Unless there is more effort, it will be necessary to expand production onto fragile lands, or currently forested lands, with great environmental damage. Additional investment in agricultural research should increase agricultural production potential on all continents and protect the environment.

(4) It is important that governments which discriminate against their agricultural sectors reduce the anti-agricultural bias in their public policies. I am not advocating a policy of subsidizing agriculture. The experience of a number of high-income countries demonstrated that such policies have rarely helped the intended beneficiaries and have often resulted in unanticipated adverse environmental consequences. Rather, governments should give their farmers a level playing field in which they are not asked to pay more than the world price for their inputs and receive the world price for their outputs. There is an important role for public investments in rural infrastructure, human capital and agricultural research, and for government in registering and protecting property rights and providing a legal code and fair judicial system to support the efficient functioning of a market economy.

(5) It is useful to note that very few countries in the world have solved the problem of rural poverty and food insecurity in agriculture. Increasing agricultural productivity can help, but it is not sufficient. It is necessary to augment farm income from non-farm sources either through part-time or full-time employment outside agriculture. Part of this can be in industries that supply inputs to farmers or add value to the raw products of the land. However, part of it needs to be in completely unrelated activity.

(6) A larger fraction of the world's food production is likely to move through international trade in the 21st century. Research and technology transfer have the potential to raise agricultural productivity in all regions of the world. However, because the world's population and arable land are distributed among the continents in very different proportions, we expect that Asia, in particular, and Africa, to some extent, will be larger importers of food and agricultural products in the 21st century. North and South America and Central and Eastern Europe have the productive potential, if appropriately developed, to supply this import demand. As long as the international trading system is reasonably free, so that it openly transmits price signals to suppliers and demanders in all countries, there is no reason why the system cannot ensure food security to all.