PONTIFICIAE ACADEMIAE SCIENTIARVM SCRIPTA VARIA

97

FOOD NEEDS OF THE DEVELOPING WORLD IN THE EARLY TWENTY-FIRST CENTURY

the

PROCEEDINGS

of

the Study-Week of the Pontifical Academy of Sciences
27-30 January 1999

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EX AEDIBVS ACADEMICIS IN CIVITATE VATICANA

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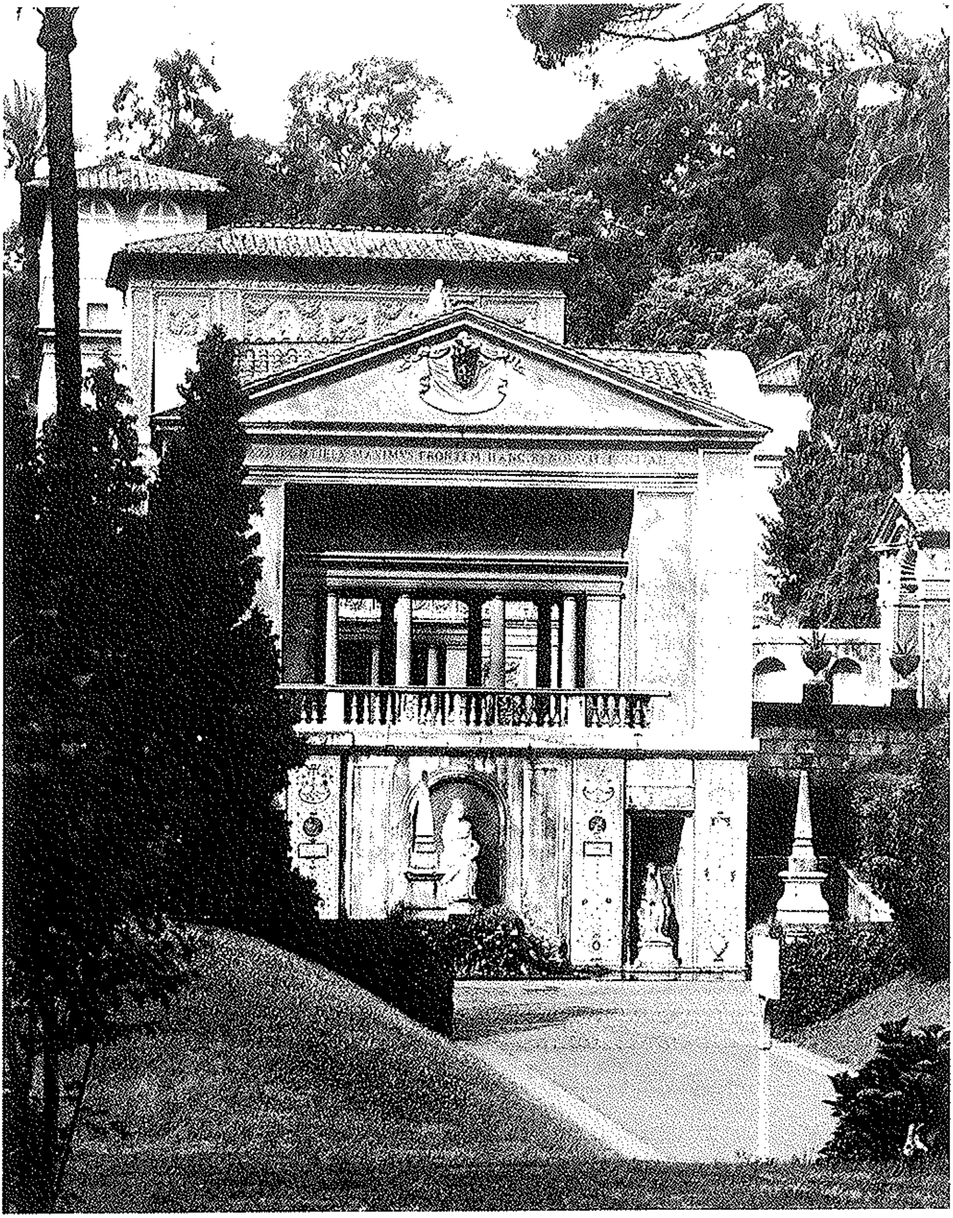

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CONTENTS

SCIENTIFIC PAPERS

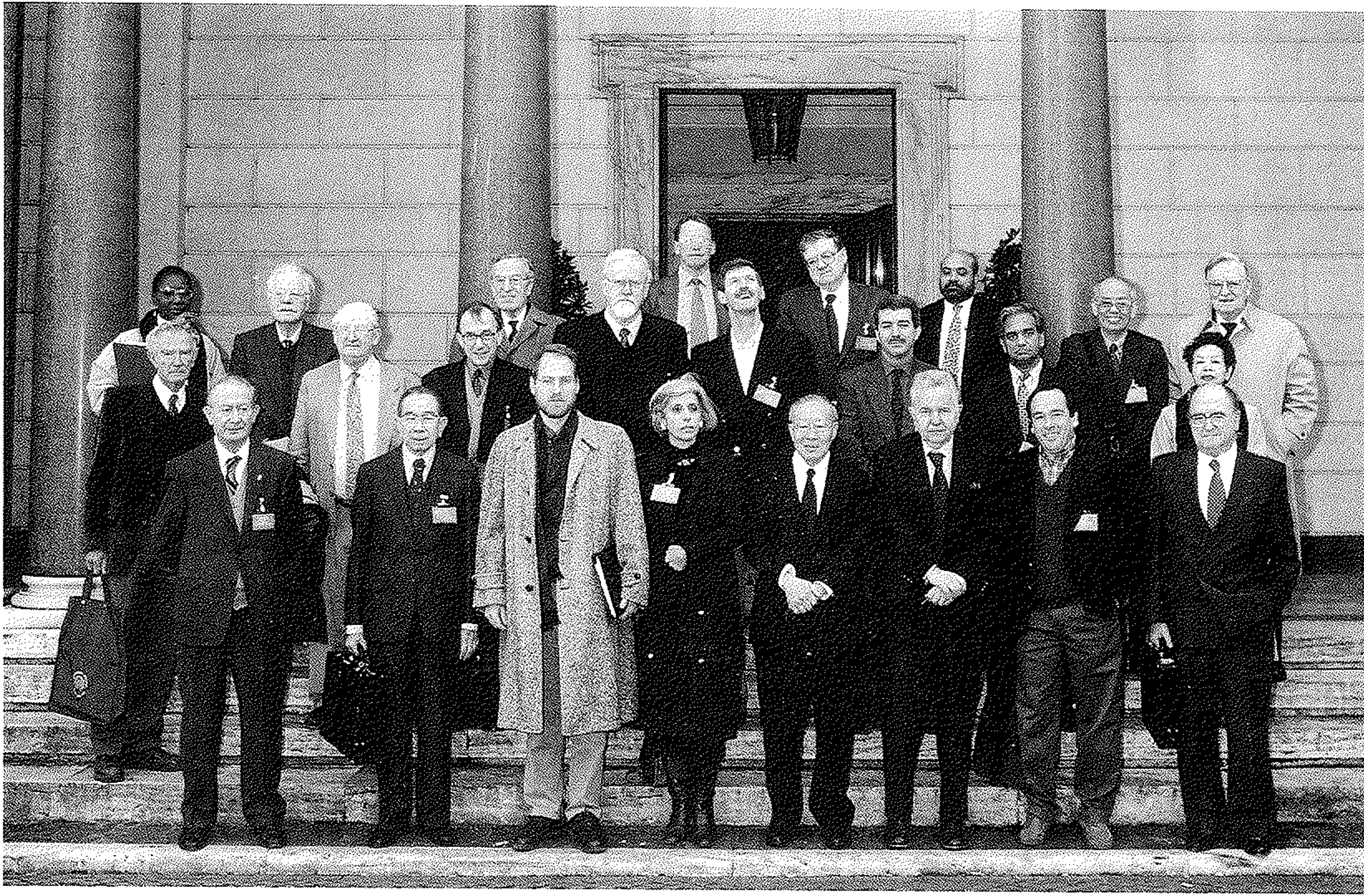
I.
Perspectives

II.
Regional Food Production and Demand Situations

III.
Technological Aspects of Food Production and Human Nutrition

IV.
Physical and Biological Factors Needed in Food Production

V.
Remedial Approaches



The Participants of the Study-Week

ACKNOWLEDGEMENTS

I would like first of all to thank the Holy Father John Paul II who continues to offer us our magnificent building in which to work and hold our meetings, in addition to the financial resources which maintain the Pontifical Academy of Sciences. I must express especial gratitude to the principal organiser of the meeting on 'food needs', Professor Te-Tzu Chang, and also to Professor Bernardo M. Colombo who kindly consented to act as joint editor and read the papers presented in this volume with great care. Thanks are extended also to Professor Nicola Cabibbo, the President of the Academy, who followed the preparations for the meeting most attentively and directed the discussions with great skill and efficacy. I world like to express a special word of gratitude to H.E. Raymond R.M. Tai, the ambassador of the Republic of China to the Holy See, for all the support he gave to the study-week. I would also like to thank my colleague, Dr. Matthew Fforde, of the Libera Università Maria SS. Assunta (LUMSA), who revised the papers in English written by non-native speakers and was also the copy-editor.

The importance of the issues and themes dealt with in these papers will be evident to all those who are interested in this vital subject. The debate which is presented here is the outcome of the contributions made by scholars and scientists who represent the major geographical regions of the world and the major branches of knowledge. Our hope is that this publication will be a contribution to a deeper human and Christian understanding of the subject to which it dedicates itself, and will stimulate a wider awareness of the very great challenges which face mankind at the beginning of the third millennium in relation to 'food needs'.

Marcelo Sánchez Sorondo

DEVELOPMENT AND HUMAN PROGRESS TO DEFEAT HUNGER IN THE WORLD

INTRODUCTION

In November 1991 the Pontifical Academy of Sciences organised a study-week on the subject of "Resources and Population". The papers and deliberations of this conference were subsequently published by the Clarendon Press of Oxford and received a great deal of attention. Since that date the Academy has during these years continued its discussion of the issues connected with underdevelopment, and in doing so has concentrated in its approach on two principal areas: the questions and problems relating to population on the one hand, and those connected with the availability of goods and resources on the other. The last conference in this field was held jointly with the Royal Society of London in 1995 and was concerned with a specific subject which has received relatively little attention from international research: maternal breastfeeding. From 27 to 30 January of this year the Academy held a study-week on *The Food Needs of the Developing World in the Early Twenty-first Century.*

The members of the Academy represent a broad spectrum of scientific expertise and knowledge and come from a wide range of geographical areas. This means that the Academy is able to secure the participation of the most important world experts, people who have rich and multifaceted professional experience and direct knowledge of particular local realities, in its discussion of the subjects which it proposes for debate. This fact was taken advantage of to the full during the study week which was held recently. This meeting gathered together agronomists, geneticists, agrarian economists, demographers, and many others – almost thirty people from ten countries, many of whom belong to important international institutions (FAO, the World Bank, the International Research Institute on Rice, the International Research Institute on Maize etc.). The conference should be seen as following on from a similar initiative held in 1988 which examined the global developments of agriculture and quality of life. On this occasion, however, the focus was more specific, and in essential terms was concerned with the so-called problem of "hunger in the world" and the solutions which can be found to this problem in the realm of agriculture.

The importance of the rapid increase in population has become less marked since the mid 1970s, but there remain major imbalances in the availability of resources between the different regions of the globe and between developed and non-developed countries. The concern of the Academy to achieve a more precise diagnosis of these differences and of their origins, and at the same time to throw light on the means by which to eliminate them, is in line with, and links up, with the condemnations which John Paul II has been repeatedly engaged in for some time, and which he stressed again during his last apostolic visit to the continent of America when he condemned continuing forms of waste and injustice.

During the four days of the conference the most recent studies on the subject were presented and discussed. The participants heard a series of objectives which were proposed in order to overcome these difficulties. Certain data in this area are truly dramatic: over eight hundred million people suffer from malnutrition, but what is most alarming is that hundreds of millions of children suffer from food deficiencies which threaten in a fundamental and irreversible way their capacity for physical and mental growth. In this context not much comfort is offered by the aim of the United Nations to reduce the number of those most in distress by a half by the middle of the next century. Regret was also expressed at the fact that in the decade 1986-1996 aid given to agricultural and rural development was reduced by about 50% in real terms. And we should be aware of the fact that this took place, it was observed during the conference, in a situation where the promotion of growth and development and the reduction of pockets of poverty favours exports from the less developed countries but at the same time also encourages the agricultural exports of the richer countries.

At the centre of the debate was so-called "food insecurity", that is to say conditions of insecurity in relation to the spatial and temporal availability of sufficient food. The possible routes to be taken to tackle this problem and overcome it were the subjects of a detailed discussion. On the one hand, a mixed array of positive and negative aspects was drawn attention to from many different angles, and on the other, detailed proposals were advanced each of whose advantages and disadvantages were assessed and evaluated. Attention was chiefly directed towards the sphere of cereals (rice, wheat, maize etc.), which are the essential basis of the food of the most underprivileged populations. The other questions which were addressed, such as lack of micronutrients and its consequences, were of lesser importance. Certain important related questions were also given prominence, such as food energy and protein requirements or the functional consequences of poor nutrition for women. A number of papers emphasised the impact of the various forms of climatic change on the agricultural production of the less developed countries. The disastrous consequences of such exceptional events as El Niño, or the floods in China, were repeatedly referred to, and reference was also often made to the trends relating to changes over time in the temperature of the soil brought about by the greenhouse effect.

A general survey of a broad number of regions brought out the different realities which are involved and illuminated a wide range of problems. It was seen that after the disastrous drought of 1970 the nine countries of the Sahel created a polical coordinating body to facilitate bilateral agreements for the rational exploitation of water resources. In contrary fashion, in central and southern Africa political instability and serious conflicts gave rise to a fall in production *pro capita*. Attention was drawn to advances in agricultural production in southern Asia, which in certain cases and in relation to certain foodstuffs, had transformed countries which were previously sufferers from food deficits into actual food exporters. But reference was also made to the fact that in regions such as Latin America increases in national production had not reduced levels of poverty and malnutrition in the poor sections of the population because of persistent inequalities in income distribution. The food is there but many people do not have the means to buy it, and even more importantly, are not even organised in a political way to make their voices heard.

With reference to the practical policies proposed to solve these difficult situations in a gradual way, objectives may be cited of primary importance which have a general purpose and which received unanimous agreement. Such objectives are, for example:

— investment in research in favour of agriculture and the rural population from an overall perspective. This research should be promoted in the right national and international forums;

— the creation or the strengthening of suitable infrastructures: the organisation of markets, transportion, storage and conservation centres, for example, but above all the extension of irrigation systems in order to achieve an improved defence of crops against meteorological conditions, in addition to the securing of access to supplies of drinking water for everybody;

— professional education and training to make those engaged in agriculture more open to innovations and more able to have a better understanding of cost/benefit ratios and to apply them in a productive way;

— education, in particular of women, and with a concomitant raising of their social status;

— the reduction of inequalities at least in terms of access to adequate food supplies;

— attention to be paid in particular to poor farmers and small concerns. Development should be fostered by internal elements and not by dependency on external relationships which come from on high;

— to respond to the challenge posed by the need to increase production and productivity; and at the same time to realise that in order to fight poverty an increase in production is not sufficient: public health, social stability and the fair distribution of wealth are subjects which must also be addressed and tackled.

A sensitive subject which gave rise to a certain anxiety was the attitude to be adopted towards biotechnology, and in particular towards genetic engineering. Quite apart from the technical aspects and a comparative assessment of respective advantages and disadvantages, the tendency towards the taking out of patents on biological material, and related increased private investments in this area, gave rise to marked concern. The need to examine the ways by which developing countries can gain access to these new forms of technology was deemed urgent. In general, this requires finding the right methods by which to balance general public interests with the search for gain by private individuals or concerns.

Bernardo M. Colombo

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SCIENTIFIC PAPERS

on

FOOD NEEDS OF THE DEVELOPING WORLD IN THE EARLY TWENTY-FIRST CENTURY

I.

PERSPECTIVES

THE PRESENT SITUATION AND COMING TRENDS IN WORLD FOOD PRODUCTION AND CONSUMPTION

PER PINSTRUP-ANDERSEN and MARC J. COHEN

Can the world meet food needs, reduce poverty, and protect the environment over the next two decades? This paper examines the current world food situation and the likely prospects over the next 20 years. It will also lay out the policies and actions needed to assure food security by the year 2020 without sacrificing the sustainable management of natural resources.

We define food security as access by every person to enough food to sustain a healthy and productive life, in accordance with the principle that everyone has a basic human right to access to adequate food and nutrition and general human dignity. As our host for this meeting, His Holiness Pope John Paul II, stated in his remarks at the opening of the World Food Summit, held across the river just over two years ago,

> In the analyses which have accompanied the preparatory work for your meeting, it is recalled that more than 800 million people still suffer from malnutrition and that it is often difficult to find immediate solutions for improving these tragic situations. Nevertheless, we must seek them together so that we will no longer have, side hy side, the starving and the wealthy, the very poor and the very rich, those who lack the necessary means and others who lavishly waste them. Such contrasts between poverty and wealth are intolerable for humanity.[1]

CURRENT STATE OF GLOBAL FOOD SECURITY

According to the Food and Agriculture Organization of the United Nations (FAO), 828 million people in developing countries lack adequate access to food (table 1). This represents 19 percent of the population of the

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[1] The statement of His Holiness can be found on the World Food Summit homepage, accessible through <http://www.fao.org>.

Table 1. *Number and proportion of undernourished people in developing-country regions* (millions of people and percentage of population).

Region	1979-81		1990-92		1994-96	
	Number	%	Number	%	Number	%
Sub-Saharan Africa	148	41	196	40	210	39
Near East & North Africa	27	12	34	11	42	12
East and Southeast Asia	379	27	289	17	258	15
South Asia	303	34	237	21	254	21
Latin America and the Caribbean	48	14	64	15	63	13
All Regions	906	28	822	20	828	19

Source: FAO (1998).

developing world. The number of undernourished people in the developing countries increased between 1990-92 and 1994-96, from 822 million, but the undernourished proportion of the population declined slightly, from 20 percent to 19 percent. Despite this mixed picture during the first half of the 1990s, both the absolute number and proportion of undernourished people were below the levels of 1979-81, when 906 million people, or 28 percent of the developing world's population, suffered from inadequate access to food.[2] These figures do not include people facing serious problems of access to food in the countries in transition from centrally planned to market economies, nor low-income people in the developed countries who must rely on insecure public assistance programs and private charity.

The regions of the developing world display varying patterns between 1979-81 and 1994-96. Throughout this period, a substantial majority of the undernourished people has remained in the greater Asia-Pacific region (East, Southeast, and South Asia) – 75 percent in 1979-81, 64 percent in 1990-92, and 62 percent in 1994-1996. In South Asia, the substantial progress of the 1980s was reversed in the 1990s, due to the persistence of poverty, rapid population growth, and failure to make food security a high policy priority.

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[2] Food and Agriculture Organization of the United Nations, *The Sixth World Food Survey* (Rome: FAO, 1996); FAO, 'The State of Food and Agriculture', posted at <http://www.fao.org/unfao/bodies/council/c1115/w9751e.htm>, accessed October 21, 1998.

The trends in Sub-Saharan Africa are worrisome as well. The region's undernourished population has grown throughout the 1980s and 1990s, while the percentage of the total population with inadequate access to food has barely declined. Nearly half the countries in the region experienced increases in the proportion of the population that is undernourished between 1990-92 and 1994-96, and due to high rates of population growth in many African countries a declining proportion of undernourishment still translates into higher absolute numbers of undernourished people. Widespread poverty, environmental degradation, declining food production *per capita*, and violent conflict accompanied by displacement of millions of people all contribute to food insecurity.

In the Near East and North Africa, the proportion of the population that is undernourished has not changed since 1979-81, while the population has grown substantially. As a result, the number of people with inadequate access to food has risen significantly.

It is important to note that in the greater Asia-Pacific region, as in the Near East and North Africa and Latin America, most countries reduced the undernourished proportion of the population during the first half of the 1990s. Food insecurity is closely associated with poverty, and the poorest developing countries have not experienced any decline in either the numbers or percentage of undernourished people.

Of particular concern is the problem of malnutrition among preschool children. Failure to obtain adequate nutrition during the early years of life can mean permanent physical and mental damage, and malnutrition is a factor in over 5 million child deaths each year. Nations that do not assure that all their children meet their nutritional needs sacrifice future productive workers, scientists, creative artists, and political leaders.

According to the World Health Organization (WHO), 167 million children under the age of 5 in developing countries are malnourished. More than half of these children live in South Asia, where 49 percent of all children under five suffer from malnutrition (figure 1).[3]

These figures on chronic undernutrition and child malnutrition in developing countries tally those who consume less than the minimum number of calories needed for a healthy and active life. At present, nutritionists generally agree that if a person takes in enough calories, he or she will also get the necessary protein. However, an adequate calorie intake does not guarantee that a person will also meet requirements for micronu-

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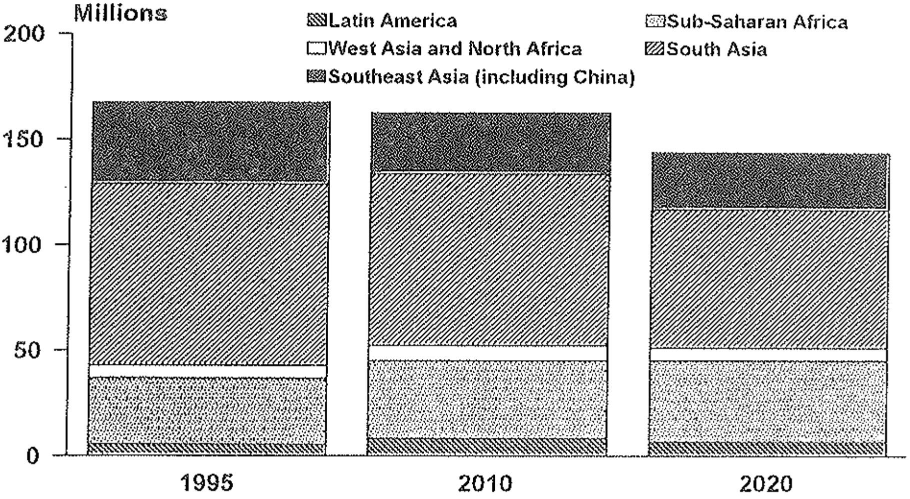
[3] WHO data on the number of children in 1995 whose weight is more than two standard deviations below the standard weight for their age set by the U.S. National Center for Health Statistics, posted at <http://www.who.int>, accessed September 17, 1998.



Source: World Health Organization, *WHO Global Database on Child Growth and Malnutrition*, WHO/NUT/97.4 (Geneva: WHO, 1998); IFPRI IMPACT Projections.

Fig. 1. Number of malnourished children (0-5 years old), 1995, 2010, and 2020.

trients – vitamins, minerals, and trace elements. WHO estimates that nearly 2 billion people worldwide suffer from anemia, including 58 percent of pregnant women in developing countries. Anemia often results from inadequate iron intake, and can lead to increased maternal and newborn mortality, impaired health and development of infants and children, limited learning capacity, impaired immune systems, and reduced school and work performance. Nearly 1.6 billion people suffer from iodine deficiency disorders, which include goitre (enlargement of the thyroid gland), brain damage, and severe mental retardation.[4]

By one estimate, micronutrient malnutrition (sometimes called "hidden hunger") results in disabilities, lost lives, and reduced productivity that cost developing countries as much as 5 percent of gross domestic product.[5] Despite the huge numbers of affected people and this severe impact, inexpensive public health interventions could significantly reduce these problems if governments have the will to implement such programs. Salt iodization

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[4] Data posted at <http://www.who.int>, accessed July 27, 1998; United Nations Administrative Committee on Coordination/Subcommittee on Nutrition, *Third Report on the World Nutrition, Situation* (Geneva, ACC/SCN, 1997).

[5] 'Small Miracles: World Bank Report Cites Major Gains from Minor Nutrients', *World Bank News*, 15 December, 1994, p. 3.

can virtually eliminate iodine deficiency, and providing pregnant women with iron sulfate tablets can greatly reduce the incidence of anemia. At IFPRI, we are leading a global initiative in collaboration with other international agricultural research centers to breed micronutrient-rich staple crops.

On the supply side, cereal production remains the key figure to be concerned about, as cereals account for about 60 percent of dietary energy supplies in developing countries, and the figure is even higher in the poorest developing countries.[6] Global cereal production rose above the long-term trend for the second consecutive year in 1997, with record wheat and rice harvests. This bounty followed the shortfalls and escalating prices of 1993-95. It is estimated that production fell by 2 percent in 1998, requiring some draw-down of stocks. However, the *ratio* of world cereal stocks to world cereal utilization is expected to remain in the 17-18 percent range that FAO considers "safe", due to the bumper harvests of 1996-97 and reduced import demand stemming from the Asian economic crisis.

There are a number of sanguine trends. Cereal production declined in the countries FAO has designated "low-income food deficit" in 1997, and global food aid fell to a historical low of 5.3 million metric tons in 1996-97. Estimated shipments for 1997-98 were at about the same level. The supply outlook remains unfavorable in many developing countries, due to a combination of adverse weather and violent conflict in Sub-Saharan Africa, the twin blows of El Niño and the economic crisis in Asia, and the devastating hurricanes that hit Central America. In September 1998, FAO estimated that 30 developing countries faced food emergencies. In 1998-99, the prospects are that food aid tonnage will increase substantially, due to the combination of increased emergency needs, weak commercial demand in Asia, relatively low international prices, and substantial stocks overhanging domestic markets in exporting countries.

Despite this mixed short-term picture, global food production remains more than sufficient to provide everyone with the required minimum number of calories if the available food were distributed according to needs. Hunger persists not because of inadequate food availability, but because poor people cannot afford to buy all the food they need and do not have access to the resources to produce it for themselves.[7]

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[6] FAO, *The Sixth World Food Survey.*

[7] 'Assessment of the World Food Security Situation, Report Prepared for 24th Session of the Committee on World Food Security', posted at <http://www.fao.org>, accessed May 20, 1998; 'FAO Forecasts Replenishment of World Cereal Stocks to Minimum Safe Levels', June 23, 1998, posted at <http://www.fao.org/news/global/gw9817-e.htm>, accessed August 6, 1998; FAO, *Food Outlook* No. 5, 1998 (Rome, FAO, November 30); FAO, *Foodcrops and Shortages* No. 4 (Rome,

PROSPECTS TO 2020[8]

IFPRI's International Model for Policy Analysis of Commodities and Trade (IMPACT) projects the future world food situation under several scenarios. In the most likely scenario, the world will continue to produce enough food at least until 2020 to meet the demand of people who can afford to buy it, and real food prices will continue to decline (figures 2 and 3). However, without significant changes in policy, high levels of malnutrition and food insecurity will persist, and the degradation of natural resources will continue, as poor people continue to lack access to the food they need.

Food Insecurity

IMPACT projections indicate that 143 million preschool children in developing countries will still be malnourished in 2020, or just 14 percent fewer than in 1995 (figure 1). Child malnutrition is expected to decline in all developing regions except Sub-Saharan Africa, where the number of malnourished children could climb 24 percent over the 1995 level, to reach 39 million. Also, depending on the severity of the current economic crisis in Asia, another 3 to 15 million children could be malnourished by 2020.

FAO projects that the total food-insecure population in the developing world will fall to 680 million by 2010, with the proportion declining to 12 percent. No projection is available for 2020. Food insecurity is likely to increase in Sub-Saharan Africa and the Near East and North Africa region, even as it declines in other developing regions. By 2010, 70 percent of food insecure people will live in Sub-Saharan Africa and South Asia (figure 4).[9]

There is likely to be a gap between food production and demand in several parts of the world by 2020. Demand is influenced by population growth and urbanization, as well as income levels and associated changes in dietary preferences. In Sub-Saharan Africa, the population growth rate has exceeded

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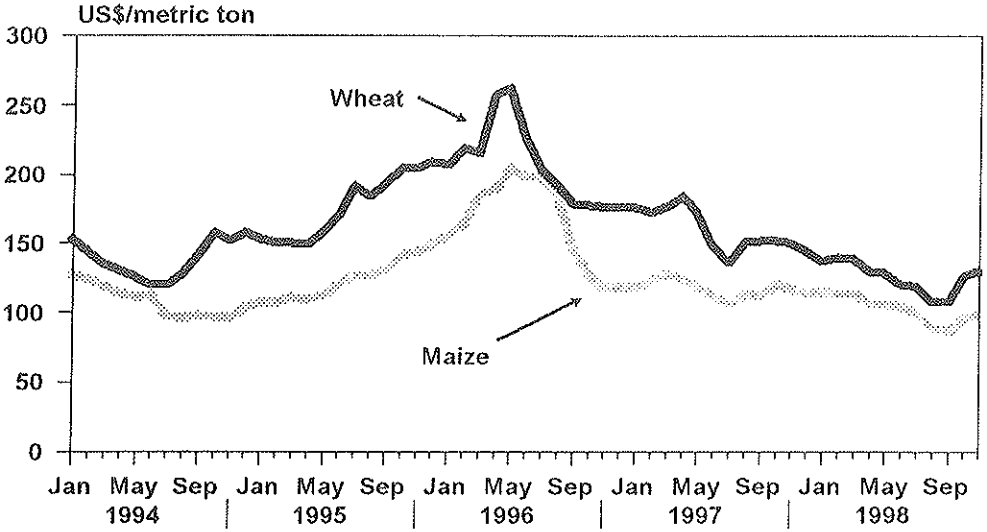
FAO, September 1998); Per Pinstrup-Andersen, Rajul Pandya-Lorch, and Mark W. Rosegrant, *The World Food Situation: Recent Developments, Emerging Issues, and Long-Term Prospects*, 2020 Vision Food Policy Report (Washington, IFPRI, 1997).

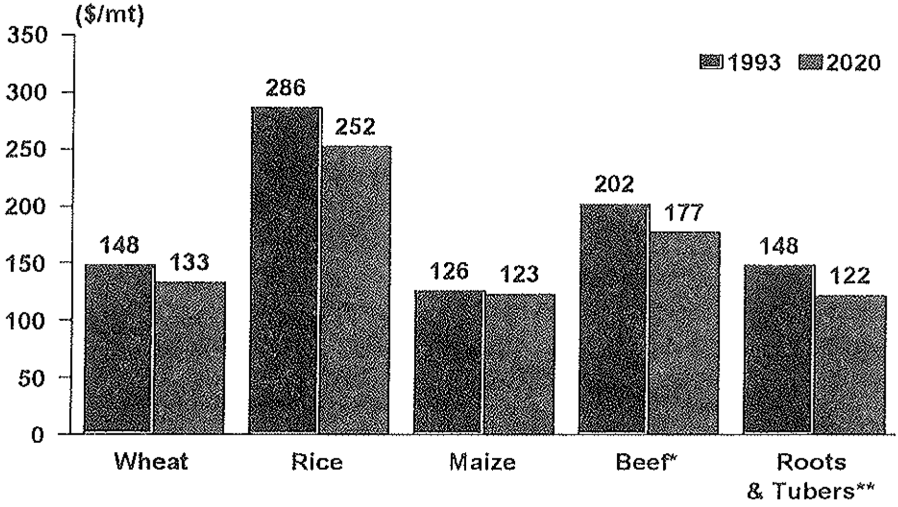
[8] Unless otherwise noted, this section is based on Pinstrup-Andersen, Pandya-Lorch, and Rosegrant; Mark W. Rosegrant and Claudia Ringler, 'Asian Economic Crisis and the Long-Term World Food Situation', paper prepared for the International Agricultural Trade Research Symposium, June 26-27, 1998; and Mark W. Rosegrant, Nancy Leach, and Roberta V. Gerpacio, 'Alternative Futures for World Cereal and Meat Consumption', paper prepared July 1998.

[9] FAO, *Food, Agriculture, and Food Security: Developments Since the World Food Conference and Prospects*, World Food Summit Technical Background Document No. 1 (Rome, FAO, 1996).



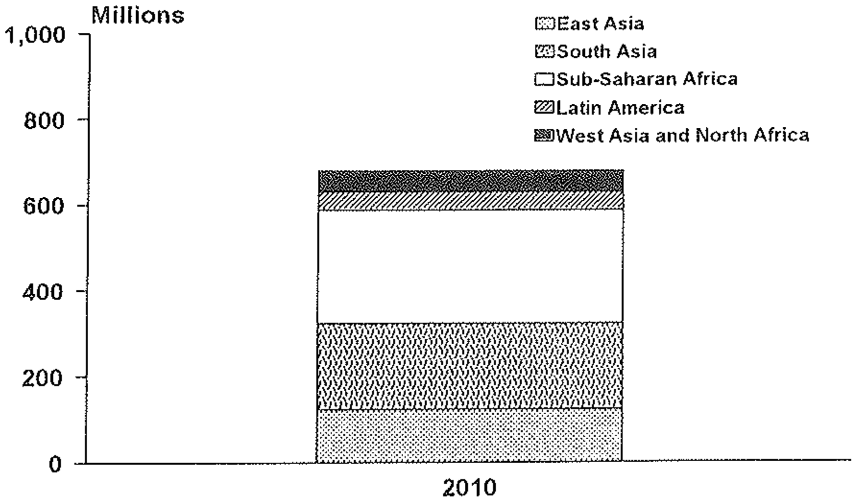
Source: World Bank 'Commodity Price Data Monthly Series' (Washington, D.C.: World Bank, Commodity Policy and Analysis Unit, monthly).

Fig. 2. Average monthly wheat and maize prices, 1994-98.



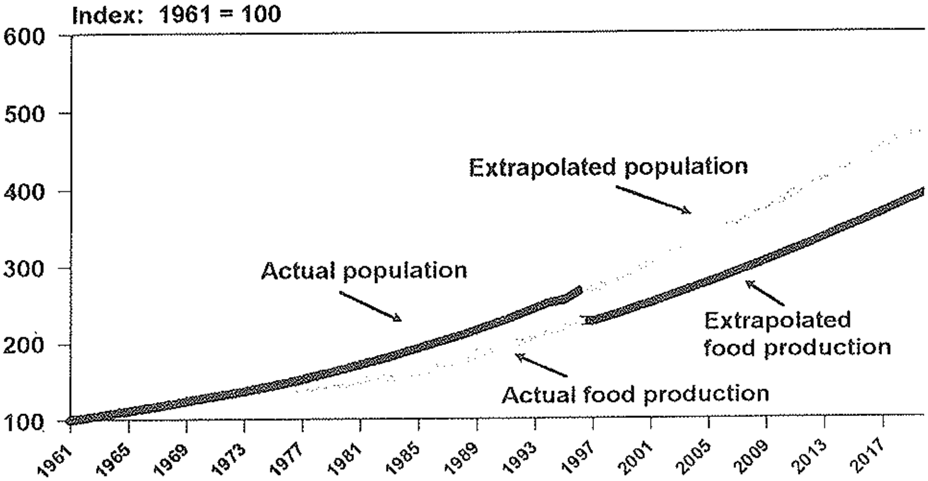
Source: IFPRI IMPACT projections.
Notes: * Beef prices are $/100 kg; ** Used 1990 data instead of 1993.

Fig. 3. Projected real world prices (in 1990 dollars).



Source: Food and Agriculture Organization of the United Nations, *Food, Agriculture, and Food Security: Developments since the World Food Conference and Prospects*, World Food Summit Technical Background Document 1 (Rome, FAO, 1996).

Fig. 4. Projected number of food-insecure people: 2010.



Source: Data for 1961-96: Food and Agriculture Organization of the United Nations, FAOSTAT database, <http://faostat.fao.org> (accessed August and September 1997); extrapolations for 1997-2020: IFPRI estimates, FAOSTAT.

Fig. 5. Actual and extrapolated population and food production indexes for Sub-Saharan Africa, 1961-2020.

the rate of growth in food production since the early 1970s and the gap is widening, resulting in declining *per capita* food production (figure 5).

Demographic Factors

According to United Nations projections, under the most likely scenario world population will reach 7.5 billion in 2020, an increase of 27 percent over the mid-1998 population of 5.9 billion. The developing world is presently home to 80 percent of the world's people. Since 98 percent of projected population growth between 1998 and 2020 will take place in developing countries, people in the developing world will account for 84 percent of the global populace by the latter year (figure 6).[10]

The developing world's urban population, which is growing quite rapidly, will double, to 3.4 billion people between 1995 and 2020 (figure 7).[11] Urbanization brings changes in diets due to new constraints on women's time and new lifestyles. When people move to cities, they generally shift from diets based on roots, tubers, sorghum, millet, and maize to rice and wheat, which require less preparation time, and to more meat, milk, fruit, vegetables, and processed foods.

Income Growth and Poverty

IMPACT projections indicate favorable income growth in all developing regions through 2020, but income inequality is likely to persist within and between countries. Poverty is likely to remain entrenched in South Asia and Latin America, and to increase considerably in Sub-Saharan Africa.

Meeting Increased Demand

IMPACT projects global demand for cereals to increase by 42 percent between 1993 and 2020, with developing countries accounting for 84 percent of the increase. By 2020, developing countries will account for 66 percent of total global cereal demand and 62 percent of global meat demand, compared to 58 percent and 47 percent, respectively, in 1993. Linked to growing developing country demand for meat will be increased cereal feed demand (figures 8 and 9).

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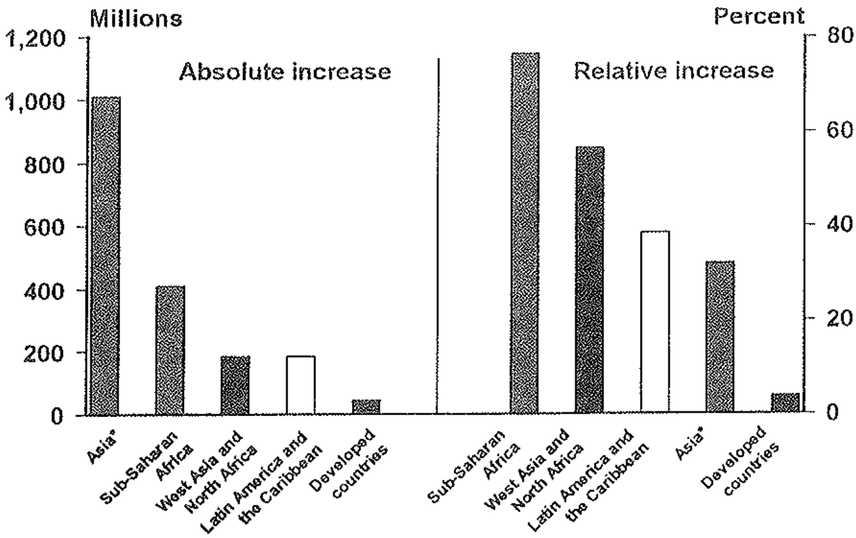
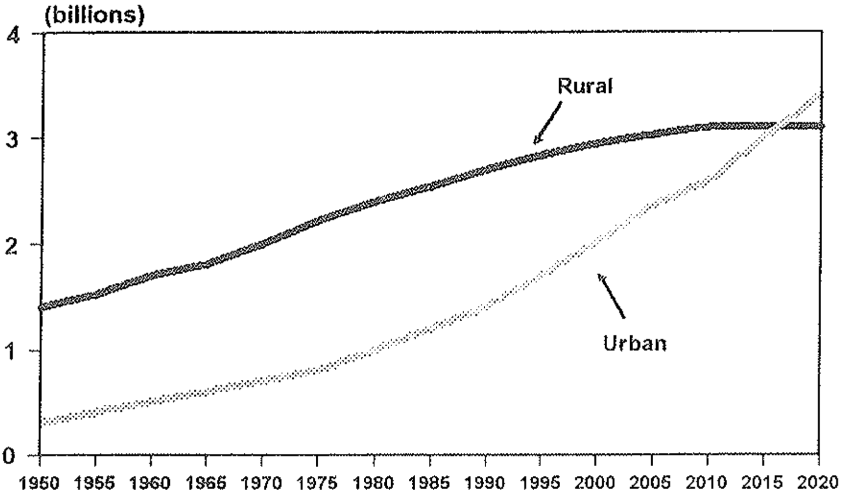
[10] United Nations Population Division, *World Population Prospects: The 1998 Revision* (electronic version, 1998).

[11] United Nations Population Division, *World Urbanization Prospects: The 1996 Revision* (New York, United Nations, 1998).



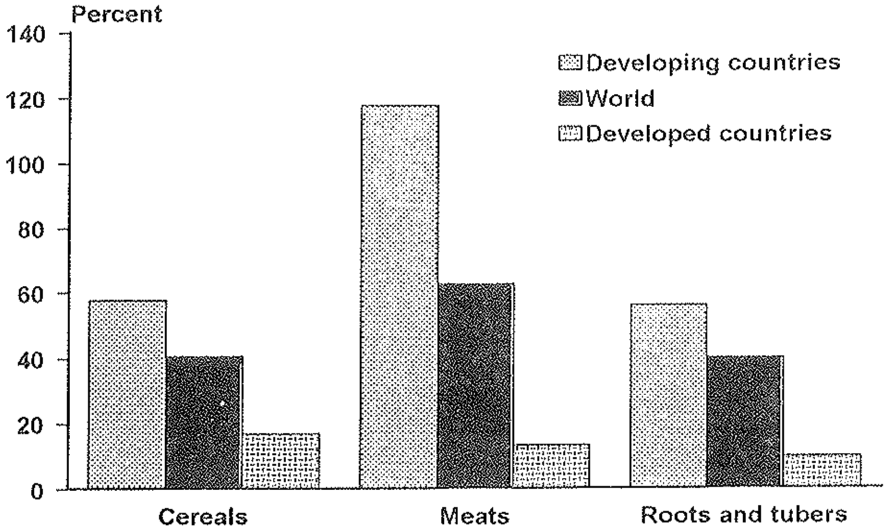
Source: United Nations Population Division, *World Population Prospects: The 1998 Revisions* (Electronic version, 1998).
Notes: Medium-variant projections. * Asia includes developing Oceana, Afghanistan, former Soviet Central Asia, and Iran; excludes Japan.

Fig. 6. Absolute and relative population increases, 1995-2020.



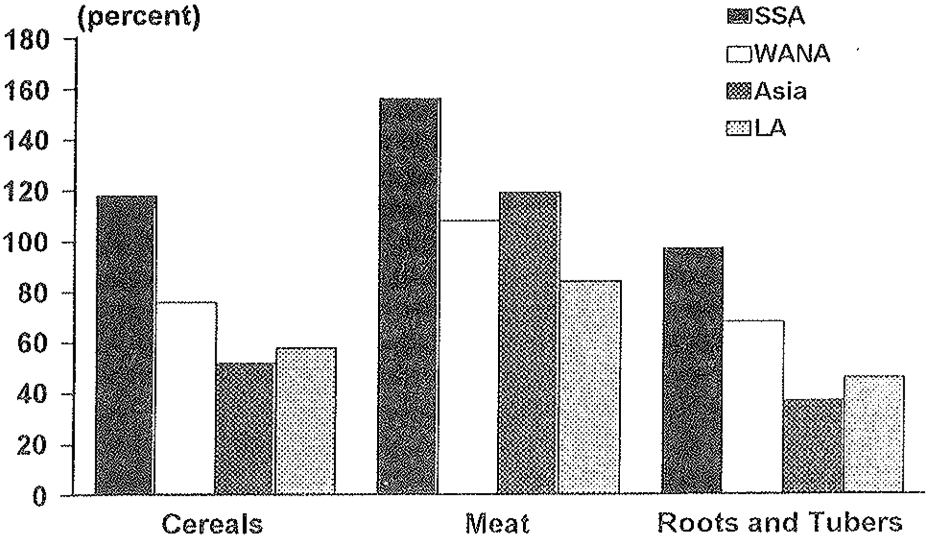
Source: U.N. Population Division, *World Urbanization Prospects: The 1996 Revision* (New York: UN, 1998).
Note: Medium-variant projections for 1990-2020.

Fig. 7. Urban and rural population in developing countries, 1950-2020.



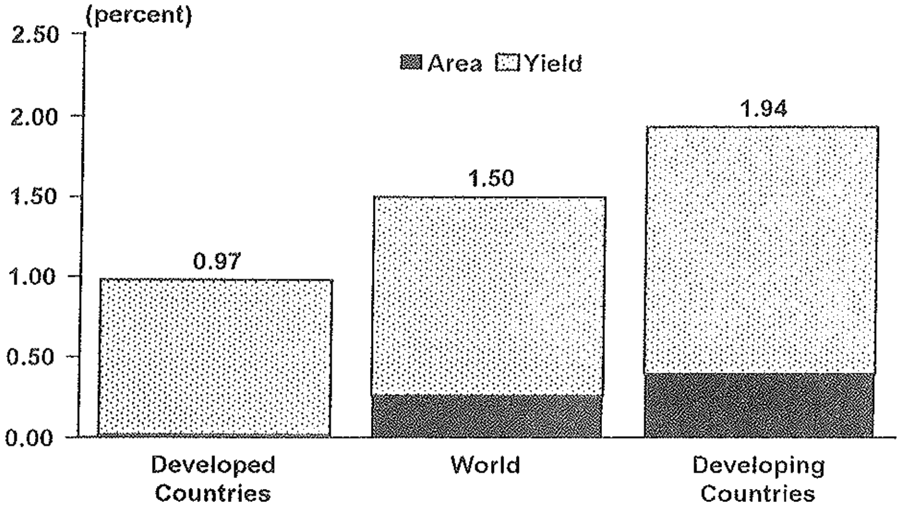
Source: IFPRI IMPACT simulations.

Fig. 8. Increase in total demand for cereals, meats, and roots and tubers, 1993-2020.



Source: IFPRI IMPACT Projections.

Fig. 9. Percent increase in total demand in developing regions, 1993-2020.



Source: M.W. Rosegrant, M. Agcaoili-Sombilla, and N.D. Perez, 'Global Food Projections to 2020: Implications for Investment', Food, Agriculture, and the Environment Discussion Paper No. 5 (Washington, IFPRI, 1995).

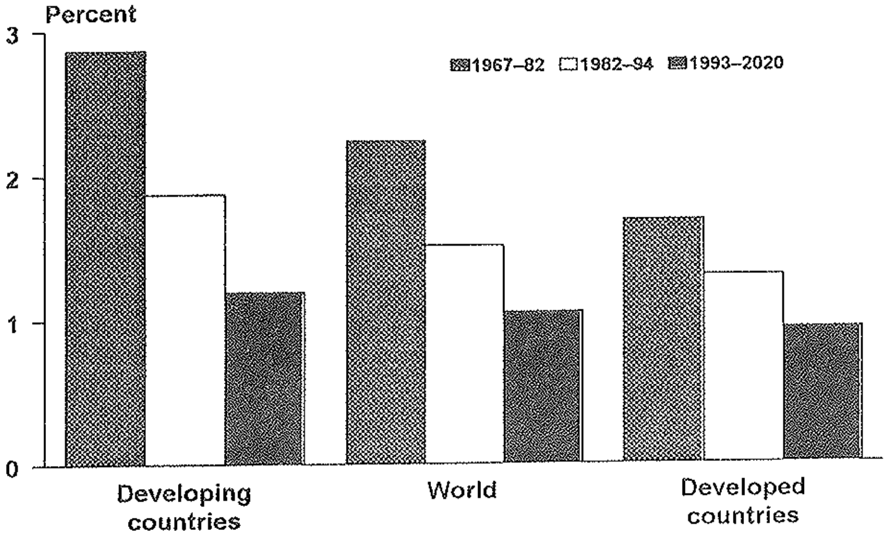
Fig. 10. Projected average annual growth rates in cereal production, 1990-2020.

Our projections indicate that the expansion in cropped areas will not account for much of the growth in cereal production to 2020 (figure 10). Thus, the burden of meeting increased demand rests on improvements in crop yields. But the annual increase in yields of the major cereals is projected to slow down during 1993-2020 in both developed and developing countries (figure 11). Cereal production in developing countries will be insufficient to meet the expected increase in demand.

The "food gap" – the difference between production and demand – is likely to more than double for developing countries by 2020 (figure 12). Poorer countries are unlikely to be able to make up the difference through commercial imports, and although global food aid tonnage is projected to rise over the short-term, it will not be adequate to fill the gap. Many millions of low-income people may not be able to afford the food they need, even if it is available in the marketplace.

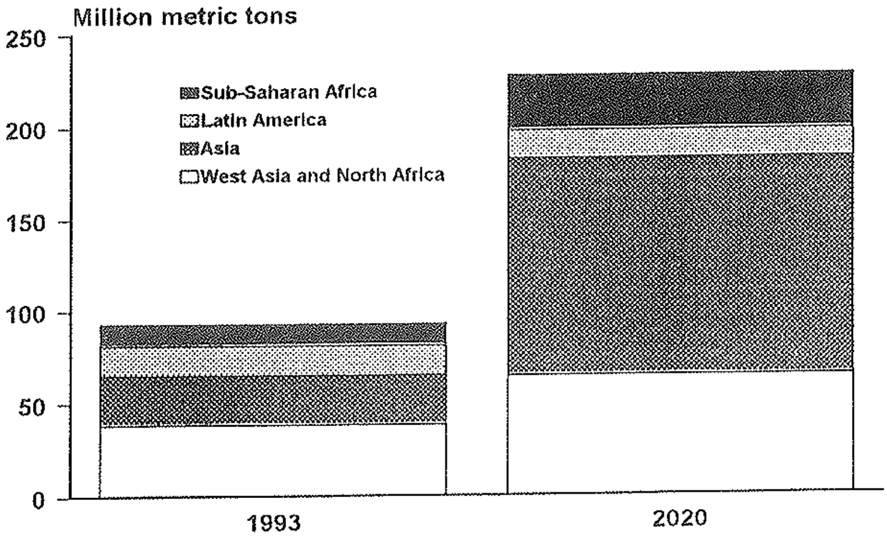
Impact of Trade Liberalization

In response to the 1994 Uruguay Round global trade agreement and structural adjustment programs enacted with the strong encouragement of aid donors, many developing countries have liberalized foreign trade in



Source: IFPRI IMPACT simulations.

Fig. 11. Annual growth in cereal yields, 1967-82, 1982-94, and 1993-2020.



Source: IFPRI IMPACT simulations.

Fig. 12. Net cereal imports of major developing regions, 1993 and 2020.

food and agricultural commodities. The developed countries have not matched this with reciprocal liberalization efforts. This asymmetry reduces benefits to developing countries and may make continued market liberalization under these conditions unviable for them. While preferential trade schemes are still in place for specified quantities of certain developing country exports, the wealthy countries have been reluctant to open up their markets to imports from developing countries of high-value commodities such as beef, sugar, groundnuts, and dairy products. Yet, in their aid donor roles, these same developed countries have encouraged developing countries to undertake structural adjustment programs that emphasize production of such high-value agricultural commodities for export.

In addition, when they signed the Uruguay Round agreement, the member countries of the new World Trade Organization (WTO) agreed to the "Decision on Measures Concerning the Possible Negative Effects of the Reform Program on Least-Developed and Net Food-Importing Developing Countries", also known as the "Marrakesh Decision", after the city where the agreement was signed. The Marrakesh Decision commits developed countries to provide compensation to poor food importing countries experiencing short-term negative consequences as a result of agricultural trade liberalization. It specifies such measures as increased food aid, access to export credits, and increased financial and technical assistance to agriculture in the affected countries. However, the Marrakesh Decision does not make any institution responsible for determining whether trade liberalization has caused harm to the poor countries, and there has been much inconclusive debate ever since. Donor countries have limited any discussion of remedial measures to food aid.[12] As already noted, increased levels of food aid are resulting partly from increased needs, but also from excess supplies in donor countries.

Fortunately, recent estimates indicate that the Uruguay Round agreement will have a very limited impact on international food and agricultural prices. The agreement will increase grain and livestock prices by between 2 and 5 percent between 1995 and 2005. This will not offset the long-term declining trend in real food prices.

Falling Aid

Meanwhile, aid to agriculture and rural development has fallen precipitously, shrinking nearly 50 percent in real terms between 1986 and 1996.

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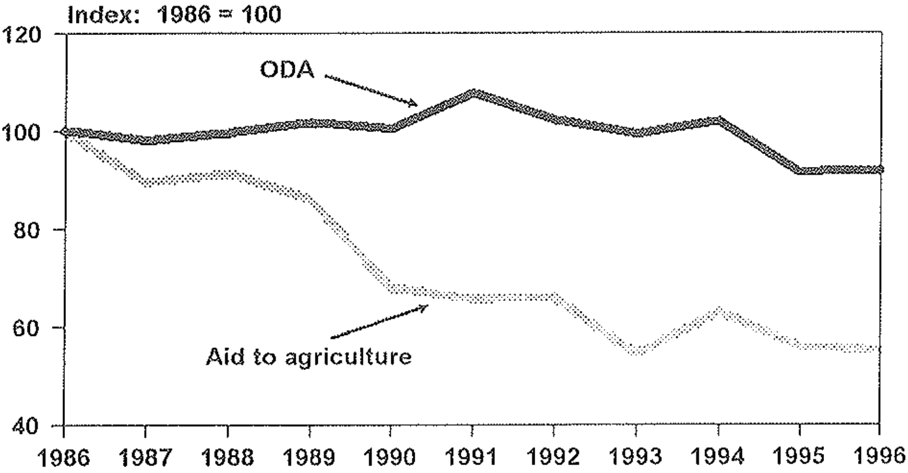
[12] Renée Marlin-Bennett, 'Agricultural Trade and Food Security', in Marc J. Cohen (ed.), *Hunger 1998: Hunger in a Global Economy* (Silver Spring, MD, Bread for the World Institute, 1997), pp. 46-53.



Source: J.H. Michel, *Development Cooperation 1997* (Paris, OECD, 1998); FAO, *Investment in Agriculture: Evolution and Prospects*, World Food Summit Background Paper 10 (Rome, FAO, 1996); and P. Narain, FAO Statistician, personal communication to authors, 6/30/98.
Notes: Provisional data for 1996 aid to agriculture.

Fig. 13. Index of real official development assistance receipts and external assistance to agriculture commitments, 1986-1996 (Inflation and exchange rate adjusted).

The decline has been much steeper than the overall reduction in development aid, which fell nearly 15 percent between 1991 and 1996 (figure 13). Ironically, our research has found that aid to developing country agriculture not only is effective in promoting sustainable development and poverty alleviation, but leads to increased export opportunities for developed countries as well, including, paradoxically, increased agricultural exports.[13]

Conflict and Food Security[14]

With the end of the Cold War, internal conflicts have proliferated in developing and transition countries. In 1997, there were 21 conflicts result-

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[13] Per Pinstrup-Andersen, Mattias Lundberg, and James L. Garrett, *Foreign Assistance to Agriculture: A Win-Win Proposition*, 2020 VisioN Food Policy Report (Washington, IFPRI, 1995); Per Pinstrup-Andersen and Marc J. Collen, 'Aid to Developing Country Agriculture: Investing in Poverty Reduction and New Export Opportunities', 2020 Brief No. 56 (Washington, IFPRI, October 1998).

[14] Ellen Messer, Marc J. Cohen, and Jashinta D'Costa, *Food From Peace: Breaking the Links Between Conflict and Hunger*, Food, Agriculture, and Environment Discussion Paper No. 24 (Washington, IFPRI, 1998); Marc J. Cohen and Per Pinstrup-Andersen, 'Food Security and Conflict', *Social Research* (forthcoming).

ing in a total of 1,000 or more deaths. This violence left tens of millions of people at risk of hunger and malnutrition, including nearly 14 million refugees, 31 million internally displaced within their own countries, and an unknown number trapped within conflict zones. In contrast, in 1985, there were about 11 million refugees and 10 million internally displaced people (figure 14).

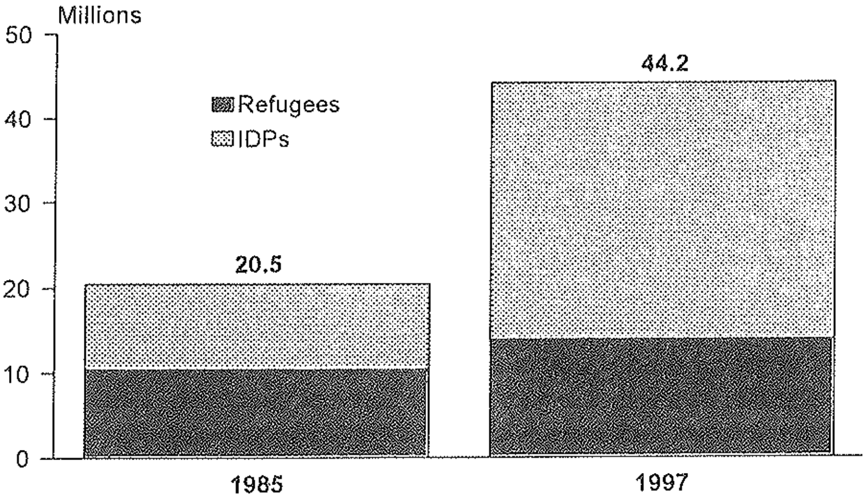
Food shortages and famine deaths occur where siege deliberately destroys food supplies and productive capacities and starves opposing populations into submission. As farming populations flee, decline, or stop farming out of fear, production falls, spreading food deficits over wider areas. Acts such as land-mining and poisoning wells have long-term effects on food production and other economic activities. Warring parties hijack food aid intended for noncombatants, using control of food to reward would-be supporters, starve out opponents, and keep conflict alive. In the Sudan, such tactics left 2.4 million people in need of emergency food assistance at the end of 1998. Our research has shown that in the 1990s conflict in Africa contributed significantly to declining *per capita* food production (figure 15).

At the same time, hunger can lead to conflict. This is particularly true in situations where competing groups face resource scarcity, economic conditions are deteriorating, and cultural norms validate the view that real or perceived injustices should be addressed through violence.

Natural Resource Management

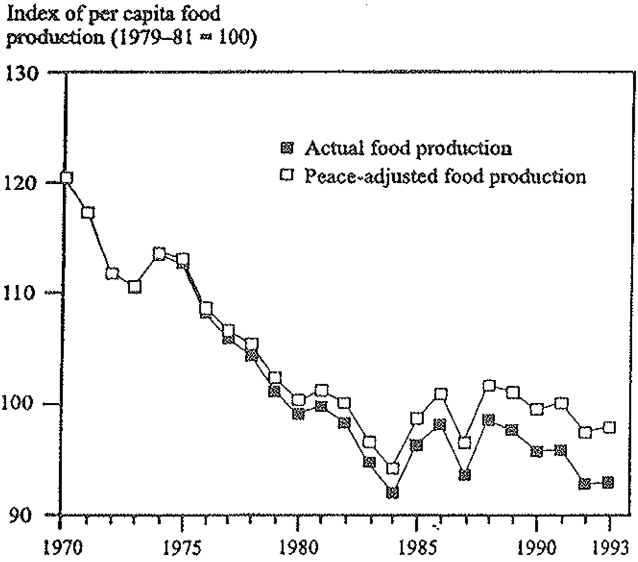
Management of natural resources, particularly soil and water, will have a considerable impact on the prospects for food security in 2020. Improved soil fertility is a critical component of low-income developing countries' drive to increase sustainable agricultural production. Past and current failures to replenish soil nutrients in many countries must be rectified through the balanced and efficient use of organic and inorganic plant nutrients and through improved soil management practices.

Although some of the plant nutrient requirements can be met through the application of organic materials available on the farm or in the community, such materials are insufficient to replenish the plant nutrients removed from the soils and thus to further expand crop yields. Reduced use of chemical fertilizers is warranted in some locations because of negative environmental effects. Nevertheless, it is critical that fertilizer use be expanded in countries where soil fertility is low and a large share of the population is food insecure. Fertilizer consumption in these countries is generally low because of high prices, insecure supplies, and the greater risk associated with food production in marginal areas. For example, on average, fertilizer



Source: U.S. Committee for Refugees, *World Refugee Survey 1997* (Washington, Immigration and Refugee Services of America, 1998); U.N. High Commissioner for Refugess, *The State of the World's Refugees, 1997* (Geneva, UNHCR, 1997).

Fig. 14. Refugees and internally displaced people worldwide.



Source: T. Marchione, 'Quantifying the Links Between Conflict and Hujnger', unpublished manuscript, 1995, 1998; FAO, *State of Food and Agriculture 1994* (Rome, FAO, 1994).

Fig. 15. Actual and peace-adjusted food production in Sub-Saharan Africa, 1970-93.

consumption in Sub-Saharan Africa is 13 kilograms per hectare, compared with 259 kilograms per hectare in East Asia (figure 16). Expanded use of fertilizers in Sub-Saharan Africa will help alleviate current production shortfalls as well as serious land degradation.

Between 1990 and 2020 global fertilizer demand is forecast to grow by 1.2 percent per year, a significantly lower rate than the 2.8 percent of the 1980s. The growth rate for developing countries will be higher – 2.2 percent – but still inadequate to meet nutrient requirements for food production and resource conservation.

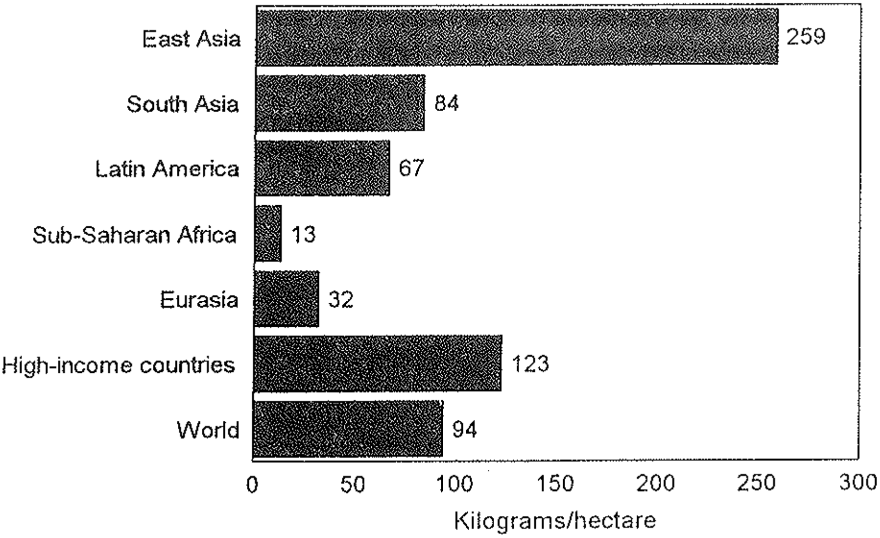
Unless properly managed, fresh water may well emerge as the key constraint to global food production. While supplies of water are adequate in the aggregate to meet demand for the foreseeable future, water is poorly distributed across countries, within countries, and between seasons. Today, 28 countries with a total population exceeding 300 million people face water stress. By 2025, the number could increase to 50 countries and a total population of 3 billion (figure 17).

Demand for water will continue to grow rapidly. Since 1970, global demand has increased by 2.4 percent annually. Our projections indicate that global water withdrawals will increase by 35 percent between 1995 and 2020, to 5 trillion cubic meters. In developed countries, most of the increased demand will be for industrial use. Developing countries are projected to increase their withdrawals by 43 percent during this period, with the share of domestic and industrial uses in total water demand doubling at the expense of agriculture (figure 18). In 1995, agriculture accounted for 72 percent of global water withdrawals and 87 percent of developing country withdrawals. Growth in irrigated area is expected to slow significantly. Although Africa's irrigated area is projected to increase by 50 percent, it will remain very low (figure 19).

The costs of developing new sources of water are high and rising. Nontraditional sources such as desalination, re-use of wastewater, and water harvesting are unlikely to add much to global water availability, although they may be important in some local or regional ecosystems.

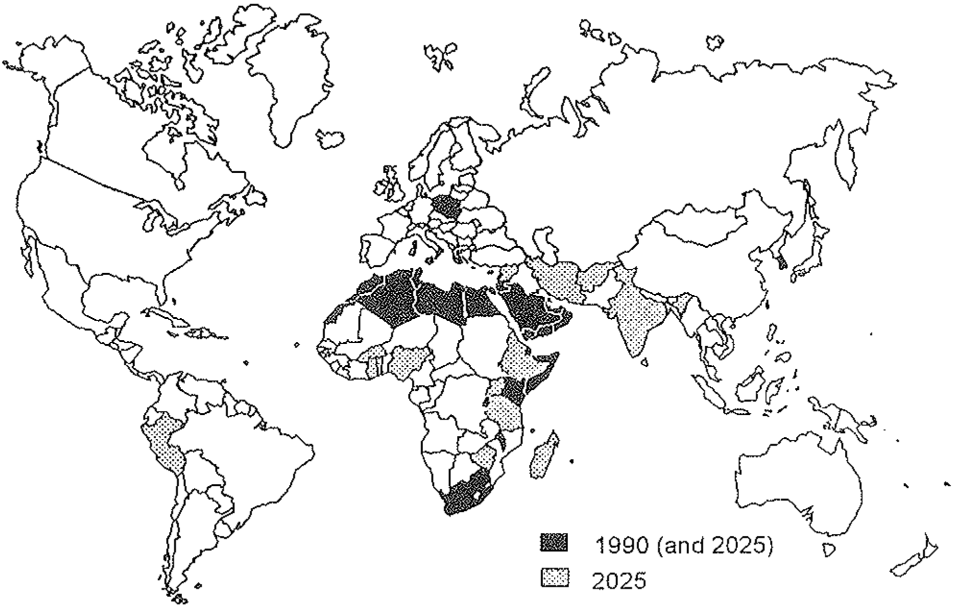
Future Uncertainty Impinges on Food Security

A number of factors that are difficult to predict will further influence the global food situation between now and 2020. These include increased grain price volatility; policy decisions and changes in lifestyles and incomes in China and India, the world's two most populous countries; and the continued impact of short-term weather patterns and long-term climate change.



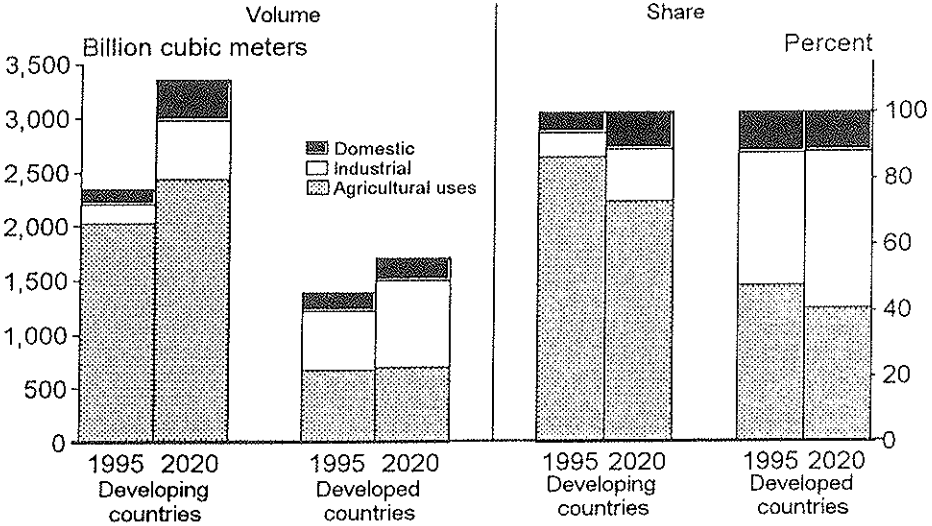
Source: World Bank, *World Development Indicators,* 1998, CD-ROM.

Fig. 16. Fertilizer use per hectare in selected regions, 1994-96.



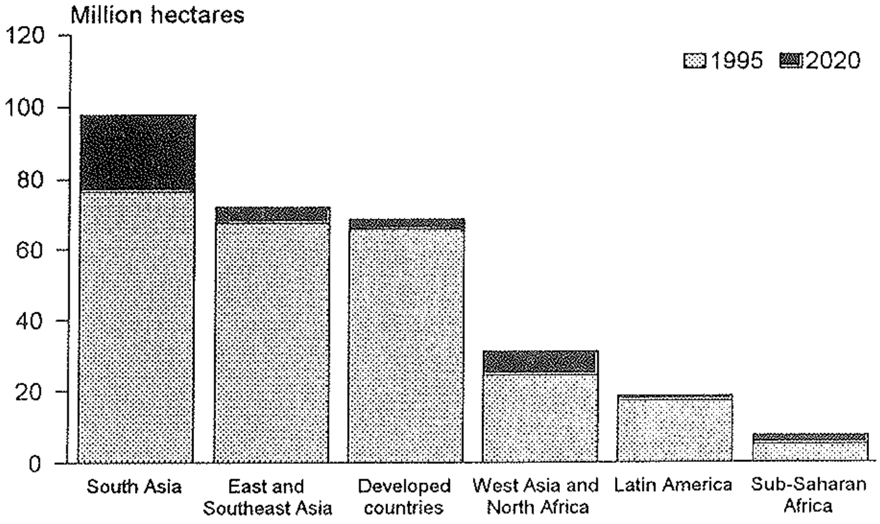
Source: Population Action International, *Sustaining Water: An Update* (Washington, D.C., 1995).

Fig. 17. Countries experiencing water stress, 1990 and 2025.



Source: M.W. Rosegrant, C. Ringler, and R.V. Gerpacio, 'Water and Land Resources and Global Food Supply', prepared for the 23rd International Conference of Agricultural Economists, Sacramento, Calif., Aug. 10-16, 1997.

Fig. 18. Water withdrawals for domestic, industrial, and agricultural uses, 1995 and 2020.



Source: M.W. Rosegrant, C. Ringler, and R.V. Gerpacio, 'Water and Land Resources and Global Food Supply', paper prepared for the 23rd International Conference of Agricultural Economists, Sacramento, Calif., Aug. 10-16, 1997.

Fig. 19. Irrigated area in major regions, 1995 and 2020.

A BRIGHTER SCENARIO *IS* POSSIBLE

There is nothing inevitable about this pessimistic outlook for food security. If the international community is willing to make food security a higher policy priority and to reverse a number of current trends, a brighter future, with benefits for developed as well as developing countries, is possible. But achieving this will require a turnaround in a number of recent trends.

More Public Investment in Agriculture and Poverty Alleviation

In South Asia, where the number of food insecure people is very high, and in Sub-Saharan Africa and the Near East and North Africa, where the numbers of food insecure people are projected to grow, governments must make enhanced food security and good nutrition for all a much higher policy priority. Aid donors should support the needed policy changes. More generally, developing countries must reverse present declining levels of public investment in agriculture. On average, they are devoting just 7.5 percent of government spending to agriculture (and just 7 percent in Sub-Saharan Africa),[15] even though in the poorer developing countries most poor people depend on agriculture either directly or indirectly for their livelihoods, and agriculture is the most viable sector for leading overall economic growth.

In particular, developing country governments must create an environment supportive of a competitive and efficient private sector. In addition, they must stress the creation and maintenance of rural infrastructure; effective markets for agricultural inputs and outputs; agricultural research and extension oriented toward small farmers, especially women, who account for the bulk of food production in many developing countries; access to credit; basic education; primary health care; nutrition policies that tackle micronutrient malnutrition as well as inadequate caloric intake; and other public goods needed to accelerate broad-based growth within and outside agriculture. Development efforts must engage small farmers and other low-income people as active participants, not passive recipients; without a sense of ownership on the part of affected people, development schemes have little likelihood of success.

Sustainable intensification of food production among small farmers in low-income developing countries will require an effective extension system.

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[15] FAO, *Investment in Agriculture: Evolution and Prospects*, World Food Summit Technical Background Document Number 10 (Rome, FAO, 1996).

In some countries, the private sector and farmer cooperatives play an important role in providing this. However, the public sector – frequently in collaboration with nongovernmental organizations – almost always has a vital role in assuring that agricultural extension services are available for poor farmers and promote sustainable management of natural resources.[16] Extension services must strengthen communications between researchers and farmers and among farmers themselves. Extension can also provide poor farmers with matching resources to contract for private or public extension services.

Agricultural Research is Essential

Public investment in agricultural research is crucial for achieving future food security. The private sector is unlikely to undertake much of the research needed by small farmers in developing countries because it cannot expect to recuperate sufficient economic gains to cover costs. Benefits to society from such research can be extremely large but will be obtained only if the public sector makes the research investments. Currently, low-income developing countries grossly underinvest in agricultural research aimed at solving small farmers' problems. These countries invest less than half of 1 percent of the value of their agricultural production as compared to 2 percent by higher-income countries (figure 20).[17]

Continued low productivity in agriculture not only contributes to food gaps in poor countries, but also prevents attainment of the broad-based income growth and lower unit costs in food production needed to help fill the gap and improve food security by boosting both availability and affordability. While efforts to improve longer-term productivity on small-scale farms, with an emphasis on staple food crops, must be accelerated, more emphasis must also be placed on research and policy that will help farmers, communities, and governments better cope with expected increases in risks resulting from poor market integration, dysfunctional or poorly functioning markets, climatic fluctuations, and a host of other factors. All appropriate scientific tools, including bioengineering, as well as better utilization of the insights of traditional indigenous knowledge, should be mobilized to help small-scale farmers in developing countries solve the problems they are facing.

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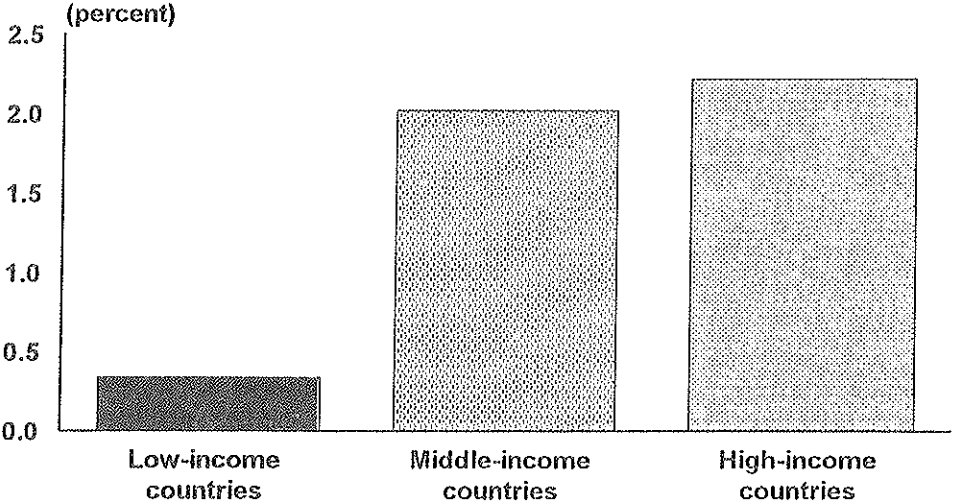
[16] William M. Rivera, 'Global Reforms and Agricultural Extension: Trends and the Public Sector', paper prepared for the Conference on Knowledge Generation and Transfer, University of California at Berkeley, June 18-19, 1998.

[17] Philip G. Pardey and Julian M. Alston, *Revamping Agricultural R & D*, 2020 Brief No. 24 (Washington, IFPRI, 1996).



Source: P.G. Pardey, J. Roseboom, and J.R. Anderson (eds.), *Agricultural Research Policy: International Quantitative Perspectives* (Cambridge, Cambridge University Press, 1991).

Fig. 20. Agricultural research expenditures as percent of agricultural GDP, 1981-85.

While both the international development assistance community and the governments of many low-income countries have failed to place sufficient emphasis on such agricultural research during the last 10-15 years, there are now signs that the international community and some developing country governments are recognizing the importance of expanded investment in agricultural development in general, and agricultural research in particular. Should these signs turn out to be correct, long-term food supplies and farmer incomes could expand considerably faster than what is currently projected.

IFPRI research shows that even minor increases in international assistance for agricultural research for developing countries could significantly accelerate food supplies while relatively small cuts could have very serious negative effects.[18] Expanded financial support of both the international agricultural research system and national agricultural research systems in developing countries is urgently needed, and it is of critical importance that information based on sound scientific evidence be used to counter the great

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[18] Mark W. Rosegrant, M. Agcaoili-Sombilla, and N.D. Perez, '*Global Food Projections to 2020: Implications for Investment*', 2020 Vision for Food, Agriculture, and Environment Discussion Paper No. 5 (Washington, IFPRI, 1995).

deal of misinformation that is currently pushing the governments of several developing countries to question public sector investments in research for agricultural productivity increases.

Reducing Unsustainable Rates of Population Growth

While population growth alone is not the main cause of hunger, as is sometimes assumed,[19] high rates of growth in Sub-Saharan Africa and South Asia have generated a momentum such that even as the rates decrease in the early twenty-first century, the number of people added will continue to increase. Population growth of the magnitude forecast will severely constrain efforts to increase income and improve welfare, while at the same time greatly increasing the need for food. Experience has shown that broad-based economic growth and greater access to resources for poor people are themselves likely to contribute to lower rates of population growth, as are improved educational opportunities for girls and empowerment of women. Access to reproductive health services for women of child-bearing years and to voluntary family-planning services, consistent with individual religious beliefs, are also important.

Dealing with the "Urban Facts of Life"[20]

IFPRI research has found that rapid urbanization in developing countries means that poverty and food insecurity are urbanizing as well. Existing data are unclear, so there is much debate as to the scope and pace of this process. Regardless of whether the center of gravity of poverty and food insecurity is shifting from the countryside to the city, it *is* clear that food insecurity has some different characteristics in cities compared to rural areas. These include greater dependence on cash income; weaker informal safety nets; increased female labor force participation, with consequences for child care and therefore child nutrition; changes in diet and exercise patterns; greater availability of public services, but questionable access for poor people; greater exposure to environmental pollution; and new, often nonexistent property rights arrangements from those found in rural areas.

The policies needed to deal with these "urban facts of life" include

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[19] For a somewhat different view on this issue from ours, see Lester R. Brown, Gary Gardner, and Brian Halweil, 'Beyond Malthus: Sixteen Dimensions of the Population Problem', Worldwatch Paper No. 143, September 1998.

[20] This section is based largely on Lawrence Haddad, Marie T. Ruel, and James L. Garrett, 'Growing Urban Poverty and Malnutrition', *World Development* (forthcoming).

improved wholesale and retail food marketing infrastructure; well targeted urban social safety net programs and efforts to make services accessible to poor people; assuring access to child care services; nutrition policies that address changing urban lifestyles, such as higher intake of fat and processed foods; improved environmental management; and development of a legal and regulatory framework that protects and promotes the livelihoods of poor urban dwellers, rather than subjecting them to harassment. Obviously, for poor developing countries, technical and financial assistance is essential for the successful enactment of such policies.

Negotiating Fair and Responsible Trade Policies

The next round of global agricultural trade negotiations, which will begin later this year, should explicitly emphasize food security and poverty alleviation in developing countries as an objective of any agreement that is reached. Developed countries must agree to open their markets to commodities from developing countries.

To fully benefit from trade liberalization, developing countries must invest in domestic infrastructure, effective and efficient agricultural input and output markets, research and technology, and a more equitable distribution of land and other productive resources. While most poor and food insecure people are expected to benefit from trade liberalization, the distribution of benefits will be determined largely by the distribution of productive assets. For developing countries, emphasis on trade liberalization must be matched by similar or stronger emphasis on rectifying domestic policies, including improved access by poor people to jobs and resources.

Conflict Prevention and Resolution

Positive scenarios for food, agriculture, and the environment depend on protecting peace where conflict is imminent, achieving peace where conflict is active, and sustaining peace where conflict has ceased. Development programs in conflict-prone areas should include explicit conflict prevention components, and relief programs need to include links to longer-term development whenever feasible. Of particular importance is research on ways to avoid conflicts in resource-poor areas. It appears that this depends at least in part on changing the resource base from one of perceived scarcity to one of comparative advantage and changing household and community contexts of hunger vulnerability to realization of greater productive potential. Although such changes might be expected to engender additional competition and possible conflict, social and cultural mores may help avoid violence by stressing fairness, justice, and conflict avoidance.

The Machakos district of Kenya is a high-population-growth, resource-poor area that has made economic transitions without bloodshed. Machakos relies on indigenous mechanisms to regulate access to land, water, and other resources and resolve conflicts. Also, the area appears to take advantage of new market and educational opportunities, increasing human and economic resources even though the natural resource base appears to be stagnating.

Political resources are also important. Effective leaders both locate new opportunities and convince people to use them. They impress on their constituents the social and economic advantages of peace relative to the destructiveness of war and may have to negotiate with warring parties to avoid being drawn into the fighting. Good leadership drawing on traditional community mechanisms can also limit competition and conflict over scarce resources and convince people to withstand short-term deprivation for longer-term political-economic stability or gains. COLUFIFA (Comité de Lutte pour la Fin de la Faim), an association of community organizations in the Casamance region of Senegal, draws on local tradition, religion, and government to help member villages in a violence-prone region of high population density to eliminate hunger and improve living standards.[21]

Forging "Win-Win" Solutions for Food Security and Sustainable Management of Natural Resources

Since natural resources are becoming ever scarcer in *per capita* terms, failure to assist farmers in increasing the productivity of the existing natural resources will result not only in increased food insecurity, but also in further degradation of natural resources, as poor people try desperately to eke out a living. Policy research can help identify policies and investments that can achieve food security in ways that are compatible with sustainable use of natural resources, thereby breaking the vicious cycle of poverty, low productivity, and growing scarcity.

One promising area in this regard has been efforts in recent years to reduce the use of synthetic pesticides. International Agricultural Research Centers have helped devise new biological pest controls, with an emphasis on protecting food crops such as cassava that are important to the diets of poor people in developing countries. In Indonesia, rice yields increased after the government eliminated subsidies on synthetic pesticides and promoted integrated pest management programs.[22]

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[21] Messer, Cohen, and D'Costa; Cohen and Pinstrup-Andersen.

[22] Montague Yudelman, Annu Ratta, and David Nygaard, *Pest Management and Food Production: Looking to the Future*, Food, Agriculture, and the Environment Discussion Paper No. 25

In view of the size and seriousness of the soil fertility problem in many low-income countries, a cost-effective fertilizer sector and policies providing incentives for farmers and communities to implement soil fertility programs are needed. In addition to the general agricultural development and poverty alleviation policies already outlined, there is a need to assure small farmers access to appropriate technology (including improved crop varieties), water, and information about effective and efficient fertilizer use in various production systems. Of particular importance to maintaining and enhancing soil fertility is the adoption of plant nutrient management practices that integrate natural and human-made sources of plant nutrients to increase productivity in an efficient and environmentally benign manner without diminishing the productive capacity of soil for present and future generations.

Reforming policies that have contributed to the wasteful use of water offers considerable opportunity to save water, improve efficiency of water use, and boost crop output per unit of water. Required policy reforms include establishing secure water rights for users; decentralizing and privatizing water management functions; and setting incentives for water conservation, including markets in tradeable water rights, pricing reform and reduction in subsidies, and effluent or pollution charges.

Strategies for achieving sustainable intensification of agriculture are critical in areas of high population density and low natural resource availability. These areas contain large and growing numbers of poor people. In many resource-poor areas, agricultural growth is the only viable poverty alleviation strategy. Worsening poverty and resource degradation due to population growth mean that investments in those areas will have substantial environmental and social payoffs.[23]

Sustaining Fragile Gains in Africa

For Africa, especially, where food insecurity is likely to increase substantially between now and 2020, the policies and priorities outlined above are vitally important if the fragile but real gains in economic growth and agricultural development of the first half of the 1990s are to be sustained

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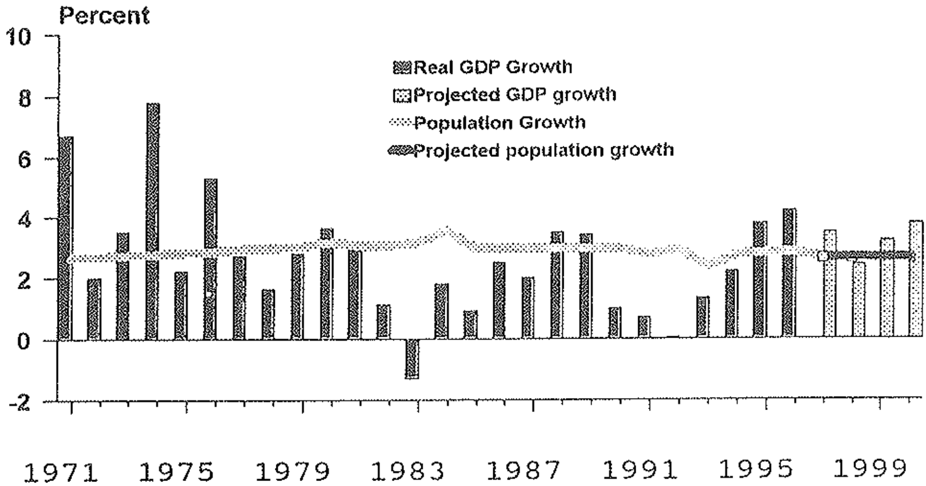
(Washington, International Food Policy Research Institute, 1998); *World Resources 1998-99: A Guide to the Global Environment, Environmental Change, and Human Health* (New York, Oxford University Press, 1998).

[23] Peter B.R. Hazell and Ernst Lutz, 'Integrating Environmental and Sustainability Concerns into Rural Development Policies', in Ernst Lutz (ed.), *Agriculture and the Environment: Perspectives on Sustainable Rural Development* (Washington, The World Bank, 1998).



Sources: World Bank, *World Development Indicators 1998*, CD-ROM; World Bank, *Global Economic Prospects 1998-99*, posted at <http://www.worldbank/org/prospects/gep98-99>, accessed 1/12/99; United Nations Population Division, *World Population Prospects: The 1998 Revision*, electronic version.

Fig. 21. Sub-Saharan Africa: Real GDP and population growth rates, 1971-2000.

and extended. Real gross domestic product growth averaged 2.3 percent for the region between 1988 and 1997, and reached 4.2 percent in 1996, the highest regional aggregate level in 20 years. However, as a result of the Asian economic crisis, weather-related shocks, political turmoil in Nigeria, and violent conflict in several countries, growth declined to 3.5 percent in 1997, and is estimated at 2.4 percent in 1998 (figure 21). Despite this disappointing picture over the past two years, the good news is that since the mid-1980s some African governments have decided to make agriculture a higher priority. Open markets have replaced inefficient, sometimes corrupt government grain monopolies. Ghana and Uganda have at least doubled the production of staple food crops, and other countries have achieved substantial gains in food output.

Donors' Responsibilities

For their part, multilateral aid agencies and the developed countries, particularly the seven richest industrial countries, must reverse the overall decline in official development assistance of recent years. In 1997, aid from the members of the Organisation for Economic Cooperation and Development's Development Assistance Committee, who provide 95 percent of all assistance, fell to 0.22 percent of their collective gross national product, according to preliminary figures, the lowest level ever recorded. For the United States, the figure was 0.08 percent. Only Denmark, the Netherlands, Norway, and Sweden met or exceeded the United Nations target of 0.7 percent. Most of the decline resulted from reduced aid from the seven wealthiest countries; other donors' aid has remained stable. Donors must also rethink their rather inflexible emphasis of the past two decades on less government and a smaller public sector, which has contributed to public disinvestment in agriculture in the developing world.[24]

A new study by the World Bank has shown that external financial assistance can contribute to economic growth, poverty reduction, and gains in social indicators in the recipient country, but only if there is also sound economic management and effective governance in place. While effective and efficient markets are critical to economic growth, an effective public sector is also essential to creating an appropriate enabling environment for growth, assuring equity, and achieving food security for all. Governments provide a stable macroeconomic environment, enforce law and order, and make available critical public services, such as infrastructure services and education, that cannot be well and equitably supplied by markets.[25]

CONCLUSION

It is possible to meet and even exceed the goal established at the World Food Summit: reducing food insecurity by half by no later than the year 2015. Doing this will require concerted and committed action by governments, civil society, and the international community. Failure to take the appropriate steps will result in continued low economic growth and rapidly increasing food insecurity and malnutrition in many low-income developing countries, environmental deterioration, lost opportunities for expanded international trade, widespread conflict and civil strife, and an unstable world for all.

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[24] Organisation for Economic Co-operation and Development, 'Aid and Private Flows Fell in 1997', OECD News Release, June 18, 1998, posted at <http://www.oecd.org>, accessed June 19, 1998; James H. Michel, *Development Co-operation, 1997* (Paris, OECD, 1998); FAO, 'Investment in Agriculture'; Pratap Narain, FAO statistician, personal communication to the authors, June 30, 1998.

[25] 'Assessing Aid–Overview', posted at <http://www.worldballk.org/research/aid/overview.htm>, accessed January 12, 1999.

MEDIUM-TERM OUTLOOK FOR AGRICULTURAL TRADE

HARTWIG DE HAEN and MAURIZIO DE NIGRIS

INTRODUCTION

The organizers of this study-week are to be congratulated for having put the topic of medium-term outlook for agricultural trade on the agenda of a conference which deals with the food needs of the developing world. Trade is an important vehicle which helps societies as well as individuals meet their food needs. It enables them to supplement the own food supplies by purchases from others. The poor and least developed countries, in particular, depend on imports of basic foodstuffs, and this although they are typically rural societies with the major part of their people earning their living in farming.

In the following I wish to, first, talk on the overall importance of trade in agricultural commodities. I will then discuss briefly the relationship between trade and food security. I will, thirdly, talk briefly about the process of agricultural reforms in the context of the World Trade Organization (WTO) where a new round of multi-lateral negotiations is due to begin later this year. Finally, I will present in some more detail results of a medium-term outlook on the major commodity markets until the year 2005.

1. IMPORTANCE OF INTERNATIONAL TRADE

World trade in goods and services in *1997* reached US$ 5,500 billion, of which agricultural trade amounted to US$ 462 billion and food trade US$ 306 billion. As a result of successive rounds of trade liberalization, world trade has expanded much more quickly than production. Between 1977 and 1997, world export in goods and services grew by 8.2 percent per year, while world agricultural trade expanded at 5.7 percent per year. In consequence, the world economy is more integrated today than ever before:

countries rely increasingly on trade, both as a source of earnings and as a source of supply.

Trade is a powerful and effective stimulant to rapid economic growth as it enables countries to make profitable use of their comparative advantages. Without trade, countries would have to rely exclusively on their own production; overall incomes would be far lower, the choice of goods would be far less and hunger would increase.

2. TRADE LIBERALIZATION AND FOOD SECURITY

As is well known, trade in agricultural commodities is far from being free from restrictions and barriers. Many high income countries have been protecting their domestic agriculture against competing imports through various forms of import duties and export subsidies combined with domestic support. Many countries, developed as well as developing, are also supporting domestic production in an effort to maintain a high degree of self-sufficiency. Many low income developing countries, on the other hand, have kept food prices low for their consumers and used a variety of measures to ensure a minimum supply of cheap food, including procurement from their own farmers, concessional imports and food aid. Others have taxed their agricultural commodities to generate budget revenue. All of these measures have an impact on production and/or consumption and thus on the level and direction of trade flows. It was therefore of significant importance that for the first time in the history of multilateral trade negotiations, the Uruguay Round included agriculture in agreements on trade liberalization. At the conclusion of this Round, member countries of the WTO have accepted a number of rather important steps including reductions in export subsidies, cuts in domestic support and reforms of import access conditions. They have also accepted the limitation of rejections of imports for sanitary or phyto-sanitary reasons strictly to cases that can be justified by sound scientific evidence. What contribution can this liberalization of agricultural trade make to food security?

Trade liberalization contributes to improving food security, provided domestic policies are in place to ensure that gains from trade reach the poor and to safeguard them from possible negative impacts. This positive impact on food security can be achieved by encouraging income growth, by broadening the range and variety of foods available, by reducing the risks arising from domestic production fluctuations, and by enabling food to be produced more efficiently.

Unfortunately, the conditions for these positive impacts to materialize do not always exist. Until now the world has only four years of experience with the Uruguay Round and even these years have witnessed a number of other disturbing factors, just recall the El Niño and the Asian financial crisis. Yet we can infer something from models. According to such models, the immediate consequence of reducing protection of agriculture in the high income countries will be that there are less surpluses, lower stocks and possibly higher prices than there would be otherwise. Lower levels of stocks may also make prices somewhat more volatile. Of course, if properly transmitted to the domestic farmers, higher world market prices should serve as an incentive to invest and produce more. Yet the institutional conditions for such transmission and for the related supply response are often not fully met. Moreover, even where they do exist, adjustment takes time. As a consequence, consumers may feel the rising prices immediately whereas the supply response is lagging behind. This undesirable impact was clearly recognized by the Ministers gathered in Marrakesh. In their so-called "Decision on Measures Concerning the Possible Negative Effects of the Reform Programme on Least Developed and Net Food Importing Developing Countries" they recognized that during the process of reform this group of countries might, at least initially, experience negative effects in terms of the availability of adequate food supplies on reasonable conditions.

Another growing concern of many developing countries relates to the standards which their products have to meet in order to be allowed to foreign markets, in particular markets of developed countries. Examples are standards for food safety (as set by Codex Alimentarius), for phytosanitary and animal-related safety and, if some of the proposals materialize in the next round, environmental standards. Even if these standards are founded on scientific evidence the developing countries fear their detrimental impact on the export earnings and food security of some developing countries.

3. The Process of Agricultural Trade Reforms

These concerns are not reported here to warn against further trade liberalization, but simply to indicate the adjustment needs of some of the poorest countries which may need help in the transition phase. In any case, a further opening of agricultural markets is to be expected for a number of reasons:

— Agricultural protectionism is still extensive. According to the OECD, the total transfers to agriculture in the OECD countries amount still to 280 billion US$ in 1997, which is on average US$ 32,000 per full-time farmer.

— The Uruguay Round Agreement on Agriculture (Article 20) has already foreseen that negotiations for continuing the reform process will start in late 1999.

With this in mind, the World Food Summit Plan of Action requested FAO to "continue to assist developing countries in preparing for multilateral trade negotiations in agriculture, fisheries and forestry *inter alia* through studies, analysis and training".

At this point in time it is rather difficult, if not impossible, to predict what direction the new trade negotiations on agriculture will take. Will parties simply agree to continue with the stepwise reduction of tariffs, domestic support and export subsidies as stipulated in the Agreement? Which so-called non-trade concerns will they take on? The preamble of the Agreement on Agriculture mentions as examples food security and the need to protect the environment. In fact, a number of countries have already indicated that they intend to refer to these issues and have also suggested that the multifunctional character of agriculture should be preserved as far as possible. Others, i.e. mainly export orientated countries interested in a freer and fairer trading system, have expressed the suspicion that such emphasis on the multifunctional character of agricultural could be a hidden form of arguing for continued protection of agricultural production. They do not at all disagree that agriculture performs a wide range of functions – production and income generation in rural areas, food security, environment and landscape preservation, cultural etc. – but they maintain that these functions can and should be pursued through policies that are decoupled from production incentives.

These discussions are mentioned here to indicate the uncertainty under which any forecast of market development has to be made. Regarding the continuation of the reduction commitments, it is rather premature to base the expectations on the experience of the Uruguay Round to date, since three to four years have elapsed from the start of its implementation.

A considerable number of studies analysing the impact of the Uruguay Round on principal agricultural commodities were undertaken over the past few years. In order to assess this impact, a comparison was made between projections undertaken before the UR agreements and the projections that took into account the effects of the agreements reached at Marrakesh in April 1994. These effects include the likely boost to world income deriving not only from agriculture also from concessions in other sectors as well, such as the reduction in agricultural tariffs, the concession of minimum access to exporting countries, cuts in export subsidies by major producers, and a reduction in the overall level of support provided to agriculture, including shifts from price support to direct income support for farmers.

4. Medium-term Prospects for Agriculture to 2005

The results of the latest study on medium-term prospects to the year 2005, recently concluded, were presented and discussed at the FAO Committee on Commodity Problems two weeks ago.[1]

It should be stressed that the study presents projections, not forecasts. The results are indicative of what would happen under certain explicit assumptions and are therefore conditional on the various macro-economic, demographic and commodity-specific assumptions used, all of which are subject to uncertainty.

The study presents a set of commodity projections related to a "baseline" scenario, which is based on assumptions regarding the economic and demographic conditions expected to prevail during the projection period, the most likely development of technology, normal weather conditions and no change in agricultural policies. The policy assumptions underlying the projections are based on full compliance with all bilateral and multilateral agreements affecting agriculture and agricultural trade as known at the time of preparing the projections, in particular the provisions of the Uruguay Round Agreement on Agriculture.

The assumptions on population growth are based on the latest United Nations' demographic projections which estimate that world population will expand at 1.3 percent annually between 1993-95 and 2005, down from the 1.6 percent per year recorded in the previous decade.

World gross domestic product (GDP) is expected to grow by 2.9 percent per year between 1993-95 and 2005 which represents an acceleration of economic growth compared with the previous decade. In the developing countries, GDP would rise by 4.7 percent annually despite the recent downward revision by the International Monetary Fund following the financial crisis that erupted in Southeast and East Asia in the second half of 1997.

The projections were prepared utilizing for the cereal/livestock/fats and oil complex the FAO's World Food Model. This model allows for the simultaneous determination of supply, demand, trade, stock levels and prices for all the commodities covered. The projections for the commodities not included in the World Food Model, namely cassava, tropical beverages, fruits and the agricultural raw materials were made using different methodologies, ranging from detailed econometric models to more simple analyses

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[1] *Medium-term Prospects for Agricultural Commodities: Agricultural Commodity Projections to 2005* (FAO Committee on Commodity Problems, Sixty-second Session, CCP 99/13, Rome, 12-15 January 1999).

and extrapolations of past trends, supplemented by expert judgements of FAO commodity specialists. In a number of cases, the projections were prepared jointly or in cooperation with international commodity bodies, universities and other international organizations. In both cases, judgements of commodity specialists and agricultural experts shaped the final results.

Turning to the results of the projections, the first finding is that world production and demand for the commodities covered by the study are projected to grow, in aggregate terms, at a higher pace than during the previous decade. Thus, world demand is expected to grow by 2.0 percent annually, above the rate of population growth (which is slowing down to 1.3 percent per year) and slightly above the 1.8 percent annual increase of the previous decade.

The reverse is true for the developing countries where production and demand are projected to grow less rapidly than the previous decade (i.e. 3.0 percent per year during 1994-2005 compared to 3.6 percent per year during 1984-1994. Net import is projected to grow very rapidly, that is at about 12 percent per year.

Factors determining the projected increase of world demand include the relatively strong economic growth still expected in developing countries, despite the Asian crisis and its effects on other regions, and the recovery in demand projected for some of the economies in transition. The developing countries will account for much of the growth in the overall commodity demand because of their comparatively buoyant per caput GDP expansion and the greater responsiveness of demand to income growth. By contrast, a slow growth in demand is foreseen for the developed countries, because high current per caput consumption and slow growth of population are expected to limit the demand growth rate for many commodities.

Aggregate world output is also projected to grow by 2.0 percent per year, slightly faster than in the previous decade when production grew at 1.7 percent annually. The production projections reflect factors such as increased flexibility over planting decisions, better yield-enhancing technology and some potential increases in arable land. It is expected that, in general, excess stocks will not accumulate again because of policies to curb excess production. Together these factors should allow production to keep pace with demand without significant price increases.

The slowdown in the expansion of world agricultural trade, already identified in previous FAO studies, is still foreseen despite the beneficial effects of policy reforms, but the picture is quite complex with an increase in growth rates for cereals, dairy products, tea and coffee and some raw materials. The slowdown in trade expansion is mainly due to the sharp falls in growth foreseen for fats, oils, oilmeals, meat, fruit and cotton. Overall, world agricultural trade is projected to grow by 2.2 percent per year, below the growth of 2.5 percent experienced during the previous decade. This development is likely to cause some significant adjustment problems for the exporting countries.

Firstly, the slow growth of trade may lead to greater competition among exporters and introduce new forms of protectionism that could emerge in response to a rather difficult market situation.

Secondly, combined with a slow growth of agricultural commodity markets, the net agricultural trade situation of the developing countries is expected, on the basis of these projections, to deteriorate so that they are likely as a whole to be net importers of agricultural products, particularly food, in the future. Of particular concern is the increase foreseen even at constant prices in the net food import bill of the LIFDCs, something that lends even greater urgency to incentives to boost their food production capacity through, e.g., the FAO Special Programme on Food Security. The situation of the Marrakesh Decision Groups of Least Developed and Net Food Importing Developing Countries is similar, a further increase in their food import bills is expected even at constant prices.

Thirdly, the gross cereal imports for the developing countries are projected to rise to 138 million tonnes by the year 2005 from 106 million tonnes in 1993-95. It is therefore extremely important for the international community to make sure that the developing countries, especially the low-income-food-deficit countries, will be in a position to import these volumes, otherwise the hope for a rise in per caput consumption and improved nutrition would be put in jeopardy.

Fourthly, and overall, the "baseline" projections suggest that most markets will be in fairly close supply/demand balance by 2005, providing weather conditions are normal. Overall, real prices for basic foodstuffs are projected to be marginally higher than 1993-95 levels, ignoring year to-year fluctuations. For instance, cereal prices are projected to be from 2.7 to 6.0 percent higher in 2005 than in the base period, while princes for the four different types of meat would be from 2.8 to 5.5 percent higher than in 1993-95. Increases in the order of 4 to 5 percent are expected for fats and oils and oilmeals, while more moderate increases are projected for dairy products.

Fifth, whatever the trend level that prices fluctuate around, the extent of price fluctuations is a matter of continuing concern. To gauge the extent of such fluctuations, two scenarios have been examined: – one the lower income growth scenario, which is probably more realistic, shows that 2005 prices of basic foodstuffs, after allowing for all the long run adjustments to take place, would be from 2 to 4 percent lower than those projected under the baseline scenario; – the other scenario, which assumes a widespread crop failure for all cereals, sets the shortfall in world cereal output in one year (2005) at 1.8 percent of the baseline and this leads to 15 percent real increase in cereal prices and a heavy draw-down of stocks. The particular importance of adequate global stocks to the stability of world cereal markets is illustrated by this analysis.

As mentioned earlier, there are many uncertainties surrounding the current projections. Changes in any of the assumptions adopted may significantly affect assessment of future prospects of world agricultural markets.

First of all, the new Round of Multilateral Trade Negotiations, due to start in November this year, may exert some greater effects on international markets than those already accounted for in the present projections. Also, the timing of the possible entry in the WTO of some large countries which have already applied for membership (e.g. China, the Russian Federation, the Ukraine and Saudi Arabia) and the provisions of their final agreements remain uncertain.

Second, there are major uncertainties about the speed and the extent of recovery of many Asian economies affected by the financial crisis and how they will achieve structural reforms and recovery of domestic demand.

Thirdly, the projections assume that there will not be any enlargement of the European Union of 15 countries.

Fourth, a more strict application of environmental protection policies and other non-trade issues, such as food safety and biotechnology, may exert greater effects on production methods and trade possibilities of exporting developing countries.

Finally, the outlook for world agricultural prices is also an area of uncertainty. Price variability may increase in the future, as world stocks are expected to be relatively low, compared to the past, and as weather may become unstable.

CONCLUSIONS

We do not have any firm indication on how the projected results would affect the food security of the poor. However, we still maintain the FAO longer term forecast to the year 2010 which indicates an expected decline to 680 million in the number of chronically undernourished people in developing countries as compared to 828 million estimated for the 1994-96 period.

According to the FAO study "World Agriculture: Towards 2010",[2] this

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[2] *World Agriculture: Towards 2010, an FAO Study* (N. Alexandratos ed., Rome, FAO, and Chichester, UK, J. Wiley & Sons).

decline could be achieved even though the world population will continue to grow. This represents a rather positive perspective. However, there is no reason for complacency, as the absolute number of people suffering from chronic undernourishment would still remain unacceptably high. Moreover, this number would still exceed the World Food Summit target, which is to reduce by at least half the number of hungry people in the world by the year 2015.

Therefore, beyond trade reforms, additional policy efforts and investments are needed in order to improve the prospects for a significant reduction of hunger in the world.

POPULATION GROWTH AND URBANIZATION IN THE DEVELOPING WORLD

MERCEDES B. CONCEPCION

INTRODUCTION

In November 1991, the Pontifical Academy of Sciences organized a study-week on *Resources and Population*. One of the papers presented during the meeting was that of Paul Demeny on *World Population Growth: Trends and Prospects, 1960-2020* (Colombo *et al.*, 1996). In his paper, Demeny described the demographic transition and discussed recent regional trends in population growth and its main proximate determinants, mortality and fertility. He concluded with an interpretation of these trends and considered future population prospects.

This paper will not repeat what Demeny so ably presented in 1991. Rather, the intention is to extend his paper by utilizing the latest population projections of the United Nations for the developing regions – Africa, Asia, Latin America and the Caribbean – and to discuss the process of urbanization currently taking place in these regions.

POPULATION PROJECTIONS, 1995-2150

Every two years, the United Nations prepares revised estimates and four variants (medium-, high-, low- and constant-fertility) of population projections for the world and its major areas, and provides national population size, age structure and demographic indicators for each country and territory. These biennial projections refer to the period 1950-2050. The latest revision was completed in 1996 and is referred to as the *1996 Revision* (United Nations, 1998a). However, understanding of the full consequences of fertility changes on population growth may require longer than

Table 1. *Life Expectancy at Birth for the World and its Developing Areas; Estimates for 1990-1995, Assumptions for 2020-2025, 2070-2075 and 2145-2150: Medium-Fertility Scenario.*

	1990-1995		**2020-2025**		**2070-2075**		**2145-2150**	
Area	**M**	**F**	**M**	**F**	**M**	**F**	**M**	**F**
World	**62.2**	**66.5**	**69.7**	**74.5**	**77.2**	**82.2**	**83.4**	**88.2**
Africa	50.4	53.3	62.8	66.1	74.9	79.3	81.8	86.2
Latin Am. and Caribbean	65.3	71.8	71.8	78.2	77.7	83.8	83.7	89.8
China	66.7	70.5	72.6	76.7	78.3	82.9	84.4	88.9
India	60.3	60.6	69.3	72.4	76.5	81.2	82.7	87.5
Other Asia	62.7	66.6	71.3	75.8	77.9	82.6	83.9	88.5

Source: Excerpted from table 3, *World Population Projections to 2150* (United Nations, 1998), p. 7.

50 years. Consequently, the United Nations extended the projection horizon for an additional 100 years to the year 2150 (United Nations, 1998b). Seven projection scenarios were prepared. Six are extensions of the *1996 Revision*, using as a base the population and demographic characteristics from the year 2025 or 2050 from one of the four variants of the *1996 Revision*. These six scenarios – medium-, high-, high/medium-, low/medium-, low-, and constant-fertility – vary according to the assumed trend of expected fertility. They follow from the four variants of the *1996 Revision* and are designed to be consistent, to the extent that this is possible, with the assumptions underlying the *1996 Revision*. The seventh scenario, the instant-replacement-fertility scenario, is new and is not a direct extension of the *1996 Revision*.

As a result of changing baseline data and assumptions, the population size at the start of these projections differs from those used in the earlier 1992 long-range projections (United Nations, 1992).[1] The accumulation of recent data, particularly from the Demographic and Health Surveys (DHS),

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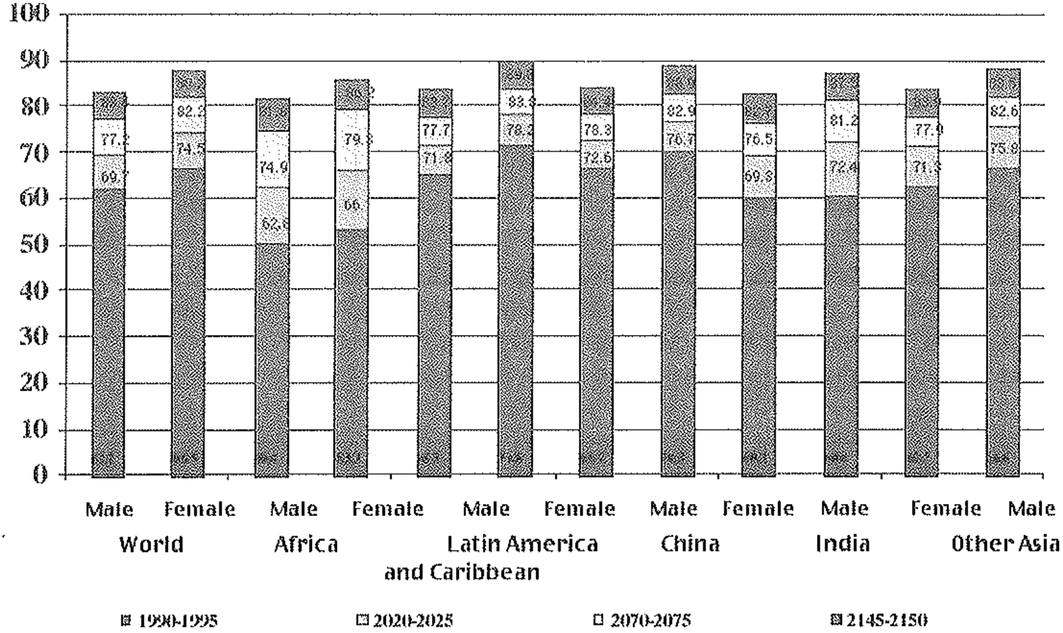
[1] Consequently, the estimated 1990 population utilized by Demeny in his 1991 paper for 1990 exceed the new United Nations 1990 estimate by 13 million and the projected 2020 population by 378 million or 5 per cent.



Source: Excerpted from table 3, *World Population Projections to 2150* (United Nations, 1998), p. 7.

Fig. 1. Life Expectancy at Birth for the World and its Developing Areas; Estimates for 1990-1995, Assumptions for 2020-2025, 2070-2075 and 2145-2150: Medium-Fertility Scenario.

point to fertility reductions in a number of sub-Saharan countries, notably Botswana, Kenya and Zimbabwe. Moreover, these surveys suggest that in several Asian countries, specifically Bangladesh, India, Pakistan, the Syrian Arab Republic and Turkey, fertility has diminished much more rapidly than estimated previously. Fertility likewise has dropped significantly in various Central American nations such as Belize, Honduras, Mexico and Nicaragua.

Data collected from the DHS as well as the earlier World Fertility Surveys (WFS) have also allowed better estimates of infant and child mortality trends. One additional modification in these latest projections is that maximum life expectancy at birth has been extended to 87.5 years for males and 92.5 years for females for each major area, with no further declines in mortality levels once these levels are reached (see table 1 and fig. 1). All seven scenarios assume the same trend in life expectancy over time owing to the fact that mortality variations have a much smaller effect on future population trends than fertility variations. The scenarios also assume no net international migration for the world's major areas after 2025.

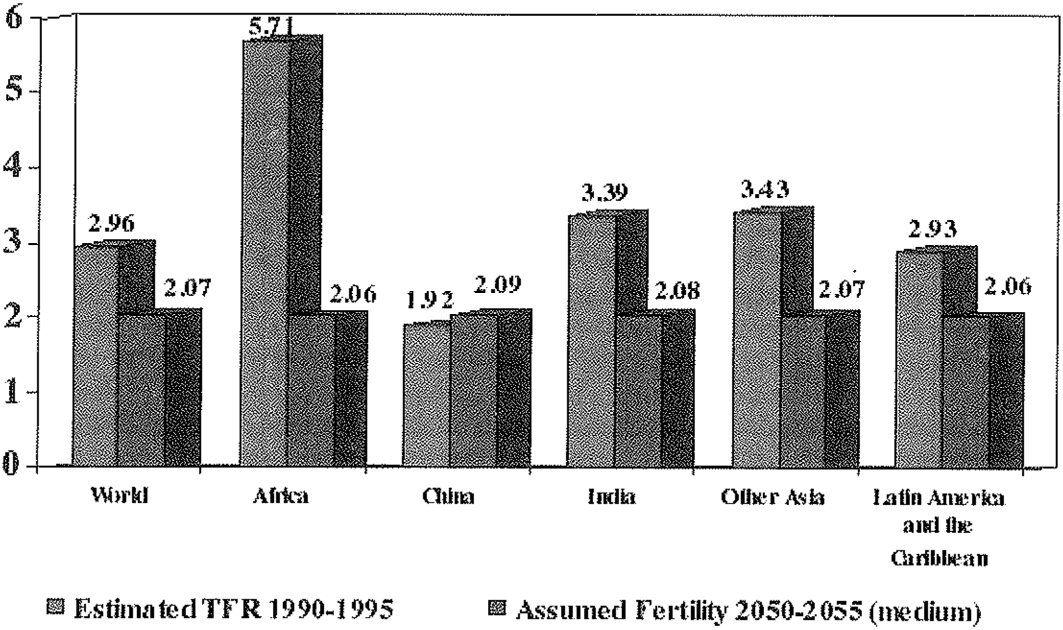
Table 2. *Estimated Fertility in 1990-1995 and Assumed Fertility in 2050-2055 for the World and Its Developing Areas: Medium-Fertility Scenario.*

Area	**Estimated TFR 1990-1995**	**2050-2055 Medium**
World	**2.96**	**2.07**
Africa	5.71	2.06
China	1.92	2.09
India	3.39	2.08
Other Asia	3.43	2.07
Latin America and the Caribbean	2.93	2.06

Source: Excerpted from table 4, *World Population Projections to 2150* (United Nations, 1998), p. 8.

For the purposes of this paper, only one scenario, the medium-fertility variant, will be presented and discussed. The underlying assumption of the medium-fertility scenario is that fertility levels will converge to the replacement level by 2050-2055. Accordingly, China is assumed to experience a rise in total fertility rates (TFR) from 1990-1995 to 2050-2055, as depicted in table 2 and fig. 2. Oceania's TFR is assumed to fall from 2.51 to 2.06. Corresponding rates in Latin America and the Caribbean are estimated to decline from 2.93 to 2.06; in India from 3.39 to 2.08; and in Other Asia from 3.43 to 2.07. Fertility levels in Africa are assumed to undergo the largest decline over the 55-year period, starting at 5.71 in 1990-1995 and eventually falling to the replacement level of 2.06 by 2050-2055.

Although fertility rates in all major areas will be at the replacement level by 2050-2055, population will still continue to grow for an extended period. This is a result of the growth momentum, the effect of age structure in propelling population growth after the fertility level is reduced to replacement levels. All major areas in the world have relatively young age distributions, an inheritance from past higher fertility levels. Even after fertility rates have fallen to the replacement fertility level, relatively large cohorts will continue to enter their reproductive ages resulting in continued population increases.



Source: Excerpted from table 4, *World Population Projections to 2150* (United Nations, 1998), p. 8.

Fig. 2. Estimated Fertility in 1990-1995 and Assumed Fertility in 2050-2055 for the World and Its Developing Areas: Medium-Fertility Scenario.

FUTURE REGIONAL POPULATION

Population Size

In 1995, the world contained 5.7 billion persons. According to table 3 and fig. 4, the world's population is estimated to reach 10.8 billion in 2150. This implies that the population of the world will have grown four times over since 1950 and more than 13.5 times since 1750.

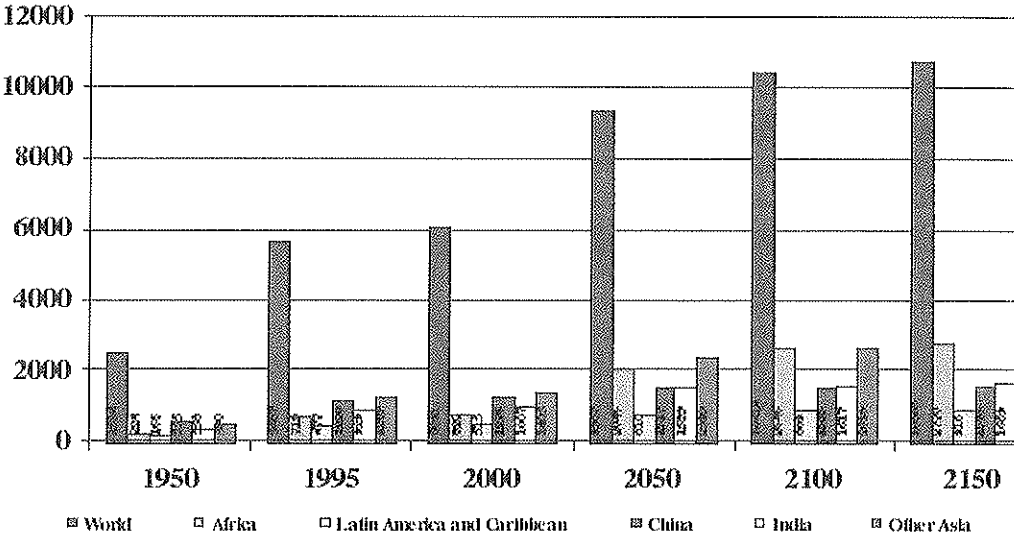
In 1990-1995, the earth's population was estimated to be growing at about 1.4 per cent yearly, falling off from the peak growth rates of about 2.0 per cent experienced between 1960 and 1975. In the future, the annual population growth rate is expected to wane to 0.38 per cent in 2045-2050, and to 0.07 per cent by 2145-2150.

Despite the reduction in growth rates, the expanding size of the base population will mean substantial additions to the number of people in the universe. It is estimated that between 1995 and 2000 the world population will grow by about 81 million people each year. This number is projected to

Table 3. *Total Population, World and Developing Regions, 1950-2150: Medium-Fertility Scenario* (millions).

Area	**1950**	**1995**	**2000**	**2050**	**2100**	**2150**
World	**2524**	**5687**	**6091**	**9367**	**10414**	**10806**
Africa	224	719	820	2046	2646	2770
Latin American and Caribbean	166	477	515	810	889	916
China	555	1220	1276	1517	1535	1596
India	358	929	1007	1533	1617	1669
Other Asia	490	1289	1405	2393	2698	2795

Source: Excerpted from table 7, *World Population Projections to 2150* (United Nations, 1998), p. 23.



Source: Excerpted from table 7, *World Population Projections to 2150* (United Nations, 1998), p. 23.

Fig. 4. Total Populations, World and Developing Regions, 1950-2150: Medium-Fertility Scenario (millions).

drop to roughly 41 million additional people per year between 2045 and 2050, and to roughly 8 million between 2145 and 2150.

If fertility rates continue at the replacement level and if life expectancies are held constant following the year 2150, the world population is expected to stabilize to slightly below 11 billion. While the population will continue to grow due to population momentum, the actual number added each year will shrink rapidly. By the year 2200, the annual population growth rate is anticipated to ebb to 0.003 per cent with less than 350,000 people added each year. According to the medium-fertility scenario the world in 1995 had just passed the halfway mark (5.7 billion or 52 per cent) of its eventual stationary size of just under 11 billion. The population will reach the 90 per cent point by 2065 and the 99 per cent mark by 2150.

The United Nations has consolidated the world's major regions into two aggregations. Group 1 includes Europe, Northern America and Oceania, corresponding to what is known as developed regions. Group 2 includes Africa, Latin America and the Caribbean, China, India and Other Asia usually classified as developing regions. Most countries in the major areas included in Group 1 are at the end of their fertility transition and are currently exhibiting relatively low levels of fertility and mortality. The majority of the countries included in Group 2 began their fertility transition later (or still have to begin) and tend to display higher fertility and mortality levels. This paper will focus on the major areas in Group 2.

The results of the medium-fertility scenario indicate that the growth in the global population between 1995 and 2150 will be primarily driven by population increments in Group 2 countries. In truth, 99.6 per cent of the estimated growth in the world population will be due to accretions in the population size of these regions. Only 0.4 per cent is attributable to countries in Group 1, as can be seen in table 3. The corresponding expansion to 2150 reveals a similar trend (99.8 and 0.2 per cent, respectively).

Africa's population expansion from 1995 to 2050 is glaring since its initial population of 719 million is projected to rise to 2.0 billion in the medium-fertility scenario. Africa's anticipated addition of 185 per cent between 1995 and 2050 will be by far the most massive of the major developing areas. As a matter of fact, whereas Europe's population was more than twice that of Africa in 1950, it is foreseen that it will contract to less than a third of Africa's population size by 2050. None of the other areas multiplies by such a degree: Latin America and the Caribbean is expected to grow by 70 per cent, that of Other Asia by 86 per cent, India's population by 65 per cent and China's by only 24 per cent. The picture does not change when the period 1995-2150 is considered.

Population Age Structure

The swelling size of the earth's population is matched by an unparalleled shift in its age structure. The medium-fertility scenario indicates that the global population will have aged tremendously by 2150. The median age will have risen from 25.4 years in 1995 to 36.5 years in 2050 and to 42.9 years a century thereafter.

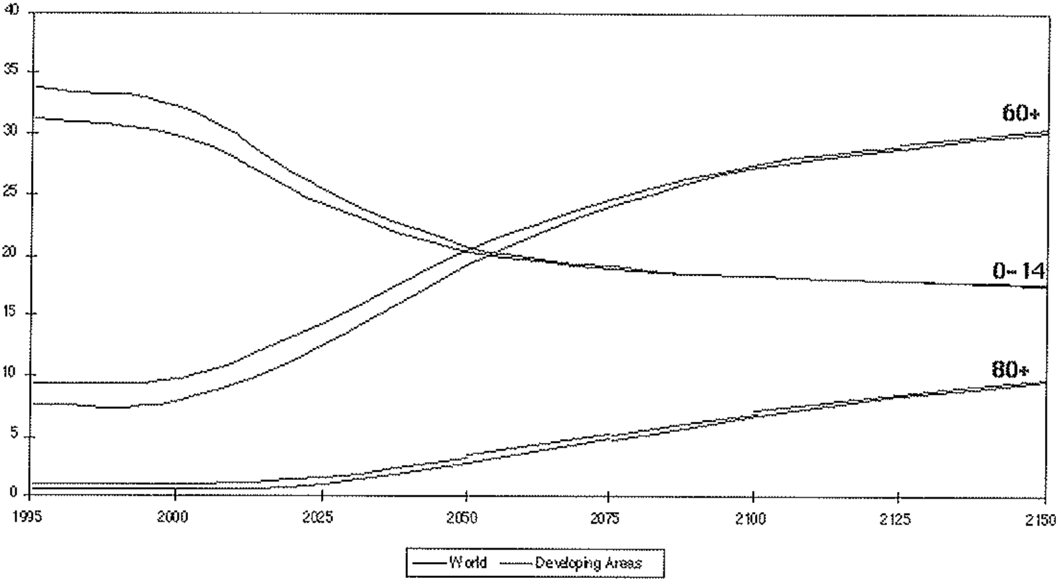
The share of the world's population under 15 years of age (the young) will contract from 31.3 per cent in 1995, to 20.5 per cent in 2050 and to 17.5 per cent in 2150 as shown in table 4 and fig. 3. Despite the increments in the world's population throughout the period 1950-2150, the numbers under age 15 are calculated to rise to 2.0 billion in 2050 from 1.8 billion in 1995, then gradually reduce to 1.9 billion by 2150.

The proportion of the global population aged 60 or above (the elderly) will expand rapidly from 9.5 per cent in 1995 to 20.7 per cent in 2050, and to 30.5 per cent in 2150. In absolute numbers, this will mean an increase in the elderly population from 540 million in 1995 to 1.9 billion in 2050 and to 3.3 billion in 2150. Indeed, although in 1995 the population under age 15 was estimated to be 3.3 times the size of the elderly population, it is

Table 4. *Share of Population in Selected Age Groups, World and Developing Areas, 1995-2150: Medium Fertility Scenario* (percentage).

Year	**World**			**Developing Areas**		
	0-14	**60+**	**80+**	**0-14**	**60+**	**80+**
1995	31.3	9.5	1.1	33.9	7.6	0.7
2000	30.0	9.9	1.1	32.3	8.0	0.7
2025	24.3	14.6	1.7	25.5	12.7	1.2
2050	20.5	20.7	3.4	20.9	19.4	2.9
2075	19.0	24.8	5.3	19.1	24.2	4.9
2100	18.3	27.7	7.1	18.3	27.4	6.9
2125	17.9	29.2	8.6	17.9	29.0	8.4
2150	17.5	30.5	9.8	17.6	30.3	9.6

Source: Excerpted from table 4, *World Population Projections to 2150* (United Nations, 1998), p. 8.



Source: Excerpted from table 6, *World Population Projections to 2150* (United Nations, 1998), p. 17, 19.

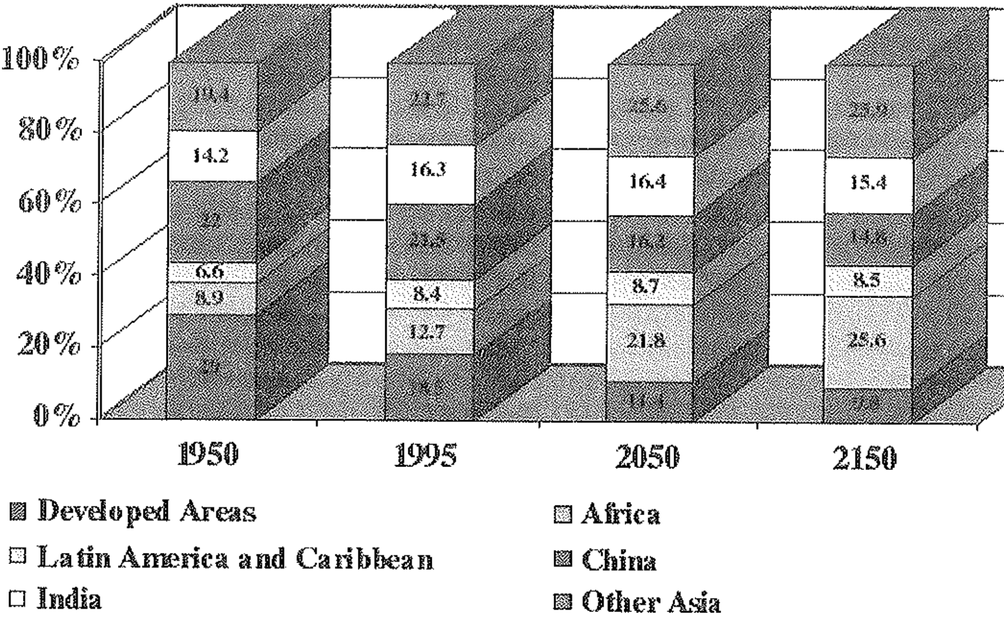
Fig. 3. Share of Population in Selected Age Groups, Medium-Fertility Scenario: World and Developing Areas (percentage).

expected that the latter will expand rapidly and surpass the number of youngsters by the year 2050. A century later, the number of senior citizens, it is forecast, will be nearly three-fourths larger than the youth.

Among the elderly age groups, it is the oldest old – those aged 80 and over – that are expected to expand the most rapidly over time. According to the projections, the oldest old will multiply by a factor of 5 between 1995 and 2050 (from 61 million to 318 million) and by 17 times by 2150, i.e., to 1,054 million.

The fraction of the developing populations in the young ages was 37.6 per cent in 1950, only diminishing to 33.9 per cent by 1995. However, this figure is expected to drop rapidly to 20.9 per cent in 2050. It is forecast that by 2150 only 17.6 per cent of the population will belong to the youth group.

The depreciation in the proportion of the youth is balanced by an enlargement in the elderly percentage. The shift in population to older ages is more pronounced in the developing world. In 1950, merely 6.5 per cent of the population of Group 2 was aged 60 or above. This proportion had only risen to 7.6 per cent by 1995. However, it is expected to more than



Source: Excerpted from table 8, *World Population Projections to 2150* (United Nations, 1998), p. 25.

Fig. 5. Percentage Distribution of the World Population, Developed Areas and by Developing Area Regions: Medium-Fertility Scenario, 1950-2150.

double to 19.4 per cent by 2050 and eventually to reach 30.3 per cent by 2150 – just slightly below the percentage for the developed regions (32.2 per cent). It is forecast that by the year 2055, the proportion of the elderly aged 60 and over will be equal that of the youth. By 2150, the number of senior citizens (2.955 billion) is expected to exceed the world population in 1965 (2.370 billon).

These population projections are based on demographic considerations. Other factors such as ecological constraints and their potential influence on the future growth of human populations have not been incorporated. Cohen's (1995) review of the estimates of the world's carrying capacity suggests the difficulty in reaching a consensus on the ultimate, ecologically-viable population size. Whether the population of the world will grow or decline in the future depends on the evolution of fertility and mortality rates. These demographic rates will themselves depend on alterations in the world population's socio-economic and physical characteristics. However, the projections presented here suggest that it is likely that the global population will continue to swell for several decades. Policies should be geared towards improving the earth's capacity to accommodate growing human numbers.

URBAN AND RURAL POPULATION SIZE AND GROWTH

The World Level

Recently revised United Nations estimates indicate that 46 percent (2.6 billion) of the world's population lived in urban areas in mid-1995 (United Nations, 1998c). This urban population is expanding three times faster than its rural counterpart. By 2006, half of the world's population are expected to be urban dwellers. By 2030, more than three fifths of the global inhabitants will be living in cities.

The gap between the developed and developing regions with respect to their levels of urbanization widened between 1950 and 1975. It has narrowed since then. In 1950, less than one fifth dwelled in urban areas of the developing regions while more than one half of the developed world population lived in cities. Twenty-five years later, 70 per cent of the developed regions' populations were urban in contrast to only 27 per cent of their developing counterparts. By 1995, a little more than one third resided in Third World cities whereas in the developed regions about three quarters of the people were urban-based. It is forecast that 57 per cent of the population in the developing regions will be urban residents by 2030, about two thirds of the level in the developed regions (84 per cent) at the same date.

As the populations of the developing and the developed regions grew and urbanized at different paces, their shares in terms of total and urban population differed and are projected to continue to vary dramatically. In 1950, the developing regions contained a major part (68 per cent) of the world population but only 40 per cent of the world's urban population. By 1975, for the first time, the share of the urban population in the developing regions surpassed that of their developed counterparts (table 5). In 1995, the developing regions' share of the world's population was 79 per cent while their share of the urban population was 66 per cent.

By 2030, these rates are expected to rise to 86 and 80 per cent, respectively. Meanwhile, the developed regions' share of the world's population fell from 26 per cent in 1975, when their share of the world's urban population was 50 per cent, to 21 per cent and 34 per cent respectively in 1995. By 2030, it is forecast that they will diminish to corresponding proportions of 15 and 20 per cent.

The world urban growth rate defined as the annual rate of change of the urban population stayed at around 3.0 per cent per year between 1950

Table 5. *Distribution of Total, Urban and Rural Population of the World Between Developed and Developing Regions, 1975-2030* (percentage).

Region	**Total**		**Urban**		**Rural**	
	1975	**2030**	**1975**	**2030**	**1975**	**2030**
World	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**
Developing	74.3	85.5	52.5	80.2	87.6	94.0
Developed	25.7	14.5	47.5	19.8	12.4	6.0

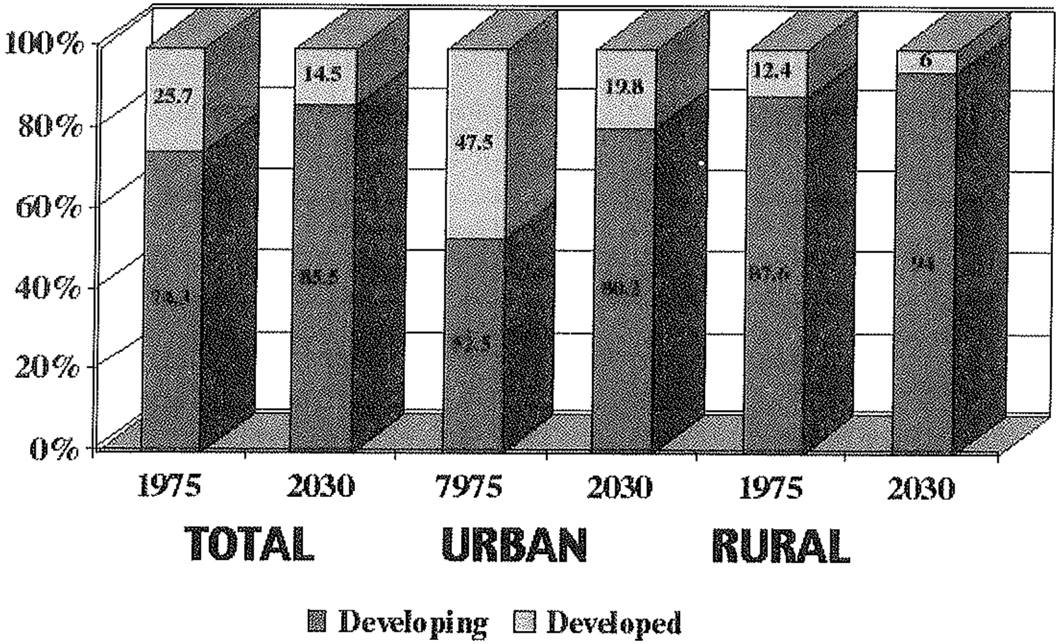
Source: Table 1, *World Urbanization Prospects. The 1996 Revision* (United Nations, 1998), p. 5.

and 1965. It dipped in the next decade, then rose slightly during the next 15 years before declining to 2.4 per cent per annum in 1990-1995. It is expected to diminish further to 1.6 per cent yearly by 2025-2030. In the developing regions, the urban growth rate reached its peak at 4.2 per cent in 1960-1965. The rate went down the following decade, moved up again during the next ten years, and has been descending since then. Reaching 3.4 per cent in 1990-1995, it is projected to drop to 1.9 per cent annually between 2025 and 2030.

In spite of the declining rate of urban population growth, the average annual increment of the world's urban population is steadily advancing. While the yearly increment during 1950-1975 was 32 million urban inhabitants, it was estimated to be 52 million between 1975 and 1995. During the first half of the nineties, 59 million new urban dwellers were added annually to the world's population. This number is predicted to reach 76 million annually in 2025-2030. Paralleling the shift of the world population from the developed to the developing regions, the latter are projected to account for a growing share of the urban increment. Of the 32 million people added annually during 1950-1975, 64 per cent belonged to the developing regions. This share rose further to 89 per cent of the 59 million in 1990-1995. It is foreseen that almost all the urban residents added to the global population will come from the Third World by 2025-2030.

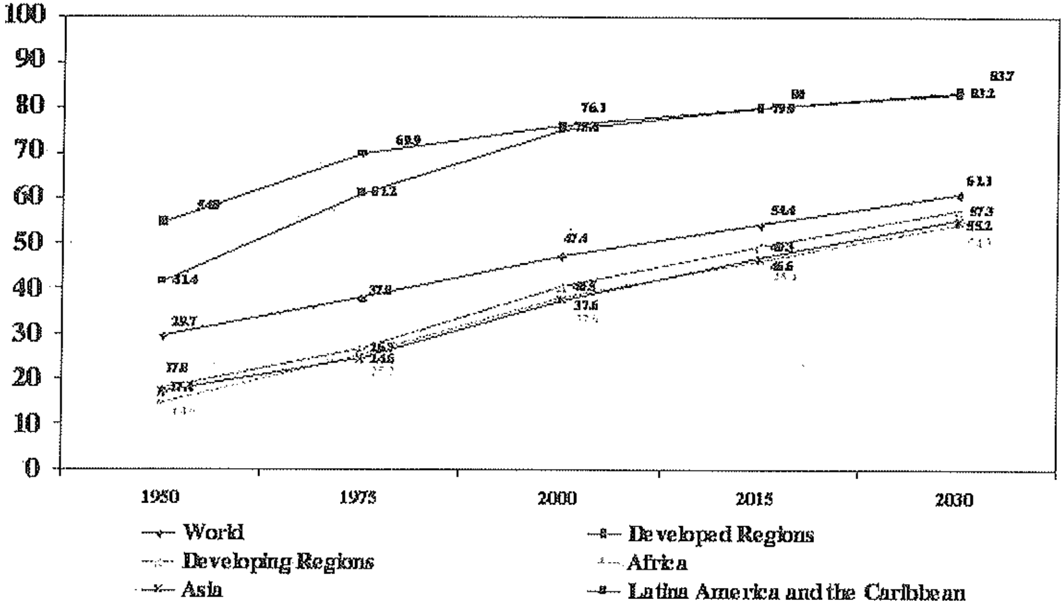
The Developing Regions

In terms of urban population size, Asia (excluding Japan) was home to 64 per cent of urban residents in the developing regions in 1995. Latin America and the Caribbean followed (21 per cent) with Africa ranking



Source: Table 3, *World Urbanization Prospects. The 1996 Revision* (United Nations, 1998), p. 5.

Fig. 6. Distribution of Total, Urban and Rural Populations of the World Between Developed and Developing Regions, 1975-2030.



Source: Excerpted from table 4, *World Population Projections to 2150* (United Nations, 1998), p. 8.

Fig. 7. Percentage of Population Residing in Urban Areas by Major Area and Region, 1950-2030

Table 6. *Percentage of Population Residing in Urban Areas by Major Area and Region, 1950-2030*

Area / Region	**Percentage Urban**				
	1975	**1995**	**2000**	**2015**	**2030**
World	**37.8**	**45.3**	**47.4**	**54.4**	**61.1**
Developed Regions	69.9	74.9	76.1	80.0	83.7
Developing Regions	26.7	37.6	40.5	49.3	57.3
Africa	25.2	34.9	37.8	46.4	54.3
Asia	24.6	34.7	37.6	46.6	55.2
Latin America and the Caribbean	61.2	73.4	75.4	79.9	83.2

Source: Excerpted from table A.2, *World Urbanization Prospects. The 1996 Revision* (United Nations, 1998), pp. 88-95.

third (15 per cent). In 1975, 13 per cent of the urban population in the developing regions were in Africa and 24 per cent in Latin America and the Caribbean. By 2030, it is probable that Latin America's and the Caribbean's share of the urban population will fall to 15 per cent while that of Africa will rise to 21 per cent.

While the greatest increase in the world's urban population has recently taken place in the developing regions, a trend expected to be maintained throughout the projection periods, massive differences are noticeable in the level and patterns of urbanization within these regions.

Africa – Among the developing regions, Africa exhibits the lowest levels of urbanization and the fastest urban growth. One in four Africans resided in urban areas in 1975. Two decades later, a little more than one third of Africans were city residents and the 50 per cent mark is expected to be reached between 2020 and 2025. By 2030, 54 per cent of Africans will live in cities (table 6).

Africa's urban growth rate, the fastest among the developing regions and in the world as a whole, is projected to remain the highest until 2030. The urban growth rate increased from 4.6 per cent in 1950-1955 to 4.9 per cent in 1960-1965 and was estimated to be 4.4 per cent in 1990-1995. Projections reveal that the growth rate will stay above 4 per cent through 2005, lessening to above 3 per cent yearly until 2020-2025, then falling to 2.8 per cent during the next quinquennium.

Latin America and the Caribbean – In 1975, 61 per cent of the population in Latin America and the Caribbean were urban. By 1995 this proportion had risen to 73 per cent. Between 1995 and 2030 it is likely that 249 million people will be added to the urban population, thus bringing the urban fraction to 83 per cent by 2030.

With the highest level of urbanization among the developing regions, Latin America's and the Caribbean's urban populations grew at 2.3 per cent yearly during 1990-1995. The urban growth rate is projected to dip below 2 per cent after the year 2000 and to reach 1.1 per cent annually in 2025-2030. This region is also the only major area whose urban growth rate has diminished steadily during each five-year period from 1950-1955 to 1990-1995, a reduction expected to continue through 2025-2030.

Asia – A little more than a third of all Asians lived in urban areas in 1995. Asia's urbanization level is similar to that of Africa as a whole. However, the regions and countries within Asia exhibit even more contrasting patterns in their urbanization levels. By 2030, it is envisaged that 54 per cent of the population of Asia's less developed areas will be urban dwellers.

Asia is characterized by large disparities in the level as well as in the pace of urbanization. As a whole, the urban population in its less developed regions grew at an annual 3.5 per cent in 1990-1995. The urban growth rate is only expected to plunge below 2 per cent after 2015-2020.

THE WORLD'S CITIES

The urban population is distributed in cities differing in size. The giant urban agglomerations, a recent phenomenon, are becoming both bigger and more profuse, housing an increasing fraction of urban residents. Concomitantly, more than half of the world's urban population continue to reside in small cities with less than 500,000 persons.

The 15 Largest Urban Agglomerations

Tokyo, with its 1995 population of 27 million, continues to be the world's largest urban agglomeration. It has occupied first place since 1970 and is forecast to retain that place until 2015. From being topnotcher in 1965, New York ranked second in 1970, then became the fourth largest city in 1995. It is expected to slip to 10th. place by 2015. After Tokyo, the world's largest cities in 1995 were Mexico City, Sao Paulo, New York and Bombay. The 15 largest agglomerations also include Shanghai, Los Angeles, Calcutta, Buenos Aires, Seoul, Beijing, Osaka, Lagos, Rio de Janeiro and Delhi. Their populations varied from 9.9 to 27 million in 1995.

The list of the 15 largest urban agglomerations is forecast to alter in both composition and population size, as is evident in table 7. Dakar is expected to join the list in the year 2000, replacing Rio de Janeiro, while Metro Manila will replace Seoul and be on the list in 2010. By 2015, the list of the 15 largest urban agglomerations is predicted to show Lagos in third place after Tokyo and Bombay.

Table 7. *The 15 Largest Urban Agglomerations Ranked by Population Size, 1950-2*

1950		**1975**		**2000**		**2015**	
Agglomeration	Population (millions)	Agglomeration	Population (millions)	Agglomeration	Population (millions)	Agglomeration	Popul (milli
New York	12.3	Tokyo	19.8	Tokyo	28.0	Tokyo	28
London	8.7	New York	15.9	Mexico City	18.1	Bombay	26
Tokyo	6.9	Shanghai	11.4	Bombay	18.0	Lagos	24
Paris	5.4	Mexico City	11.2	Sao Paulo	17.7	Sao Paulo	20
Moscow	5.4	Sao Paulo	10.0	New York	16.6	Dakar	19
Shanghai	5.3	Osaka	9.8	Shanghai	14.2	Karachi	19
Essen	5.3	Buenos Aires	9.1	Lagos	13.5	Mexico City	19.
Buenos Aires	5.0	Los Angeles	8.9	Los Angeles	13.1	Shanghai	18.
Chicago	4.9	Paris	8.9	Calcutta	12.9	New York	17.
Calcutta	4.4	Beijing	8.5	Buenos Aires	12.4	Calcutta	17.
Osaka	4.1	London	8.2	Seoul	12.2	Delhi	16.
Los Angeles	4.0	Calcutta	7.9	Beijing	12.0	Beijing	15.
Beijing	3.9	Rio de Janeiro	7.9	Karachi	11.8	Metro Manila	14.
Milan	3.6	Moscow	7.6	Delhi	11.7	Cairo	14.
Berlin	3.3	Bombay	6.9	Dakar	11.0	Los Angeles	14.

Source: Excerpted from table 3 *World Urbanizations Prospects. The 1996 Revision* (United Nations, 1998), pp. 22-22.

It is thought that Asian cities will be increasingly represented among the 15 largest urban agglomerations in each decade. In 1995, eight of the 15 largest urban agglomerations were in Asia. Projections show that by 2010 the number of Asian cities on the list will rise to nine, with Dakar moving up to 8th. place in 2010 and New York and Los Angeles in Northern America being among the world's mega-cities by 2015. No European city had reached nor is forecast to reach the size of 10 million inhabitants by 2015.

The annual growth rates of cities observed in the developing regions are higher and larger in their range than in the developed regions. Some exhibited growth rates in excess of 4 per cent per annum between 1975 and 1995. For example, Bombay grew at 4 per cent annually between 1975-1995; Dakar, at 7.4 per cent; Lagos, at 5.7 per cent; and Karachi, at 4.5 per cent. These rates indicate extremely rapid growth. The Bombay rate implies a population doubling time of 17.3 years whereas Dakar could double in 9.4 years should such a rate be sustained. On the other hand, Mexico City, Buenos Aires, Beijing, Shanghai and Rio de Janeiro grew by an average of less than 2 per cent during the period 1975-1995.

Projections for the future reveal that some cities, particularly in Asia and Africa, are expected to continue to experience high growth rates at least until 2015. Among the mega-cities, Dakar, Hangzhou, Hyderabad, Istanbul, Karachi, Lagos and Lahore are expected to grow above 3 per cent annually between 1995 and 2015. Mexico City, Buenos Aires, Seoul and Rio de Janeiro are predicted to expand by less than 1 per cent during the same period.

Fluctuations over time in the degree of population concentration and the distribution of people are influenced by several factors (Champion, 1989). Among them, some favor concentration in large cities and more urbanized regions. As a case in point, the growth of business services requires a high level of national and international accessibility and a large supply of highly qualified personnel leading to greater concentration in cities. On the other hand, other factors operate over a long term in favor of deconcentration. For example, transport and communication improvements and the expanding ownership of houses by people lead to population deconcentration.

These factors have operated in such a way that the growth of cities over time, or the "urban transition" as it can be called, evolves along cyclic lines as follows.

The first phase of city growth is characterized by fastest growth in the city core: this phase is called *urbanization*. The second phase – *suburbanization* – is characterized by the highest expansion in the ring around the city core. The third phase is *counter-urbanization* characterized by population reduction in the core and the ring, with the core losing more population than the ring. Finally, the fourth phase is *re-urbanization* with the core expanding more rapidly than the ring.

Most cities in the developed regions seem to be at the third or fourth state of this four-stage cycle growth. Some cities have completed the cycle and have started a new one. In the developing regions, Latin America in particular, some mega-cities such as Rio de Janeiro, Sao Paulo and Buenos Aires have experienced a slow-down in their population growth rate, although no real diminution of population has been observed. Mexico City, on the other hand, after experiencing a slackening in population growth between 1980 and 1990, accelerated its pace between 1990 and 1995.

The sharp slow-down of the population growth rate in some of the developing regions' mega-cities is accompanied by a steadily decreasing proportion of the urban population residing in these cities. Some of these cities are also characterized by a high degree of primacy, i.e., an important fraction of the country's urban population lives in these cities. In Mexico, 30 per cent of the urban population lived in Mexico City in 1975; in 1995, this proportion had dropped to 25 per cent. In Argentina, 43 per cent of the urban population lived in Buenos Aires in 1975; by 1995 the fraction had been reduced to 38.5 per cent. New information on mega-cities in Africa and in Asia will shed some light on the capacity of these cities to follow the same pattern as those in Latin America and the more developed regions. The passage from the second stage to the third is only possible if living in smaller cities or in the countryside is appealing. Government action and the relocation of industries may sometimes be needed for some cities to reach the third stage.

Distribution of Cities and Urban Population by City-size Class

The urban structure of a country or region may be studied by examining the distribution of the urban population in different city-size classes as well as the importance of the premier city. Five classes of cities are considered: cities of 10 million or more inhabitants; cities of 5 to 10 million; cities with from 1 to 5 million; cities with 500,000 to 1 million; and lastly, cities of fewer than 500,000 inhabitants as listed in table 8.

As described earlier, the number of cities with 10 million or more inhabitants rose from 1 to 14, accounting for 12 million (1.6 per cent) and 195.2 million (7.6 per cent) of the world urban population in 1950 and 1995, respectively.

The number of cities with from 5 to 10 million inhabitants, grew from seven in 1950 to 23 in 1995 and is expected to reach 38 in 2015. In the

Table 8. *Number of Cities and Percentage of Urban Population by City-Size Class, World and Developing Regions, 1950-2015.*

	World				Africa				Asia				Latin America and Caribbean			
	1950	**1975**	**1995**	**2015**	**1950**	**1975**	**1995**	**2015**	**1950**	**1975**	**1995**	**2015**	**1950**	**1975**	**1995**	**2015**
10 million or more																
No. of agglomerations	1	5	14	26	0	0	1	2	0	2	7	18	0	2	4	4
Percentage of Urban Population	1.6	4.4	7.6	10.6	0	0	4.1	7.1	0	5.3	8.5	13.8	0	10.9	15.7	13.1
5-10 million																
No. of agglomerations	7	17	23	38	0	1	1	6	2	7	14	21	1	2	2	4
Percentage of Urban Population	5.6	8.2	6.7	6.7	0	5.8	3.9	7.0	5.0	8.6	8.7	7.2	7.3	8.7	3.6	5.8
1-5 million																
No. of agglomerations	75	157	289	463	2	7	32	63	26	61	122	222	6	17	37	64
Percentage of Urban Population	18.7	19.9	22.0	23.6	10.5	13.0	24.2	25.3	18.9	20.5	19.9	21.1	17.1	16.2	21.4	27.5
0.5-1 million																
No. of agglomerations	106	215	337	407	4	19	35	56	40	78	148	176	5	25	45	59
Percentage of Urban Population	9.8	9.8	9.0	7.1	8.2	13.4	9.5	7.0	11.2	9.0	8.5	6.0	5.1	8.6	9.0	8.2
Under 500,000																
Percentage of Urban Population	64.2	57.7	54.7	52.1	81.3	67.8	58.4	53.6	64.9	56.6	54.4	51.8	70.5	55.6	50.3	45.4

Source: Table A.17, *World Urbanization Prospects. The 1996 Revision* (United Nations, 1998), pp. 179, 180, 182, and 185.

middle of the twentieth century only two of the seven cities were located in the developing regions. By 1995, 17 of the 23 cities of this size were found in the Third World. In 2015, 31 of the 38 cities of this size are likely to be situated in the developing regions.

The number of cities with 1 to 5 million inhabitants went from 75 in 1950 to 327 in 1995. By 2015, 463 cities are predicted to reach this size. In 1950, 32 such cities were to be found in the developing regions. In 1995, the corresponding number was 159 of the 257 cities of this size (62 per cent). By 2015, 345 of the 463 cities according to forecasts, will be located in the developing regions.

There were more cities in the 500,000 to 1 million size class than in any other between 1950 and 1995. It is predicted that 407 cities will achieve this size by 2015.

More than half of the earth's urban population currently dwell in cities with less than 500,000 inhabitants. These cities were home to 64 per cent of the world urban population in 1950. Their share is expected to drop gradually in the future.

It is very conceivable that factors shaping the "urban transition" are the same, but the processes involved vary in strength and impact between countries. The geographical position of the cities, the layout of the national territory, and the recent pace of economic growth of the countries are factors that may contribute to increasing or reducing the influence of these factors.

REFERENCES

Champion, A.G. (ed.) (1989): *Counterurbanization: The Changing Pace and the Nature of Population Deconcentration* (London).

Cohen, J.E. (1995): *How many People can the Earth Support?* (New York, W.W. Norton & Co.).

Demeny, P. (1996): *World Population Growth: Trends and Prospects, 1950-2020*, eds. B. Colombo, P. Demeny and M.F. Perutz (Vatican City, Pontifical Academy of Sciences), pp. 25-46.

United Nations (1991): *World Population Prospects 1990* (Sales No. E. 91.XIII.4).

United Nations (1992): *Long-range World Population Projections: Two Centuries of Population Growth 1950-2150* (Sales No. E.92.XIII.3).

United Nations (1998a): *World Population Prospects: The 1996 Revision* (Sales No. E.98.XIII.5).

United Nations (1998b): *World Population Projections to 2150* (Sales No. E.98.XIII.14).

United Nations (1998c): *World Urbanization Prospects: The 1996 Revision* (Sales No. E.98.XIII.6).

II.

REGIONAL FOOD PRODUCTION AND DEMAND SITUATIONS

FOOD AND NUTRITION SECURITY IN THE SAHEL: THE CURRENT SITUATION AND POLICY IMPLICATIONS FOR THE TWENTY-FIRST CENTURY

SALIMATA WADE

INTRODUCTION

The food crisis which affects most developing countries is the most unbearable situation to be found in the world today, where very many poor hunger-stricken populations and rich people are living together. The community of the Sahelian region arose from a political desire to provide a structure (CILSS) to tackle the climatic and ecological crises which emerged in the 1970s. It remains a multi-component community as regards land size, insularity, enclavement and socio-political organisation. The region's main characteristic (it is composed of 9 countries: Chad, Mali, Niger, Burkina Faso, Cape Verde, The Gambia, Senegal, Mauritania and Bissau Guinea) is its agricultural production, which varies according to different seasons with their climatic hazards (Centre Regional Agrymet, 1998). In the present paper an attempt is made to analyse the major factors that will continue to influence food supply and demand in the Sahel in the near future.

CHRONIC UNDERNUTRITION

The FAO and WHO International Conference on Nutrition (1992) indicated that 800 million people in the developing countries are chronically undernourished, meaning that their food consumption is below that required to maintain body weight and normal activities (FAO/WHO/UNU, 1985). Five years later, the UN Sub-Committee on Nutrition reported that chronic undernutrition is likely to persist at significant levels in Sub-Saharan Africa (ACC/SNC, 1997).

In the Sahel, 60 to 70% of the caloric intake derives from cereals, particularly in the rural areas. Ways to meet cereal demands by local production vary considerably from one country to another, as shown in table 1. The studies conducted by ORANA/ORSTOM during the period 1960-1979 in Six Sahelian countries showed that 90% of the energy requirement was met (ORANA/ORSTOM, 1980). In a study we conducted in an agrarian town in Senegal in 1986 (Diaham *et al.*, 1991), the mean energy supply *per capita* was between 1700-2400 Kcal; however, cereal consumption is not the only source of energy, and limiting the energy consumption to cereals is inappropriate (table 2). According to FAO, the energy supply *per capita* in the Sub-Saharan region was 2140 Kcal in 1969-71, 2100 in 1988-90 and is projected to be 2170 Kcal in 2010 (Alexandros, 1995). Meanwhile, the main characteristic of the Sahelian region lies in the seasonal variability of energy supply. During gap periods, the energetic deficit can reach up to 40-50%. In addition, variability in food consumption occurs as well, due to the different seasons, living habits (nomadic or sedentary), family size, and food distribution within families. In most Sahelian countries, the gap occurs at a

Table 1. *Security Rate of Cereal Needs from Local Production (1996-1997).*

Country	Needs (TONS)	Net production (TONS)	Rate (%)
Bissau Guinea	196.600	105.400	54
Burkina Faso	2.037.500	2.076.000	102
Cape Verde	95.200	1.100	1
Chad	980.300	716.800	73
Mali	1.920.000	1.742.700	91
Mauritania	496.600	76.500	15
Niger	2.421.600	1.905.200	79
Senegal	1.732.200	828.600	48
The Gambia	205.700	91.400	44
CILSS	**10.085.700**	**7.543.700**	**75**

Source: CILSS/DIAPER.

Table 2. *Energy Supply* per Capita *in September 1986 in the Khombole area.*

	Urban Area (Khombole)		Rural Area (villages)	
	Wolofs	Sereres	Wolofs	Sereres
Number of subjects	60	60	120	120
Energy (kcal ± SD)	2387 ± 81	2011 ± 80	1944 ± 43	1715 ± 45
Energy from (%)				
Protein	14.7	12.7	12.7	12.6
Lipid	26.8	30.0	20.4	12.1
Carbohydrates (cereals)	58.5	57.3	66.9	75.3

Source: Diaham *et al.*

time of hard labour and when food stocks are thinning out (ORANA/ORSTOM, 1980). We conducted a study on rural Senegalese farmers in order to examine the distribution of energy needs within family groups by measuring the 24-h energy expenditure in each member of the family, and found that the total energy expenditure as well as the physical activity level (PAL) were very high in all age and sex groups. PAL was between 1.7 to 2.7 (Diaham *et al.*, 1997). According to FAO/WHO/UNU these values reflect heavy physical activities. High 24-h total energy expenditure has been also reported in the Gambia (Singh *et al.*, 1989; Minghelli *et al.*, 1990, 1991) and in Burkina Faso (Bleiberg *et al.*, 1980). As energy expenditure should be used to estimate energy requirements (FAO, WHO/UNU, 1985), the projected energy supply *per capita* is far from covering needs, and thus it is probable that undernutrition is likely to persist in the Sahelian region.

Following the International Conference of Nutrition, national nutrition surveys were conducted in many developing countries (Demographic and Health Surveys: DHS). Chronic undernutrition among women and children under 5 is widespread. 16% of the women in Mali (DHS, 1995-96), 19% in Niger (DHS, 1992), 14% in Burkina Faso (DHS, 1993), and 15% in Senegal (DHS, 1992-93) have a Body Mass Index less than the 18.5 kg/m^2, which is considered as adult malnutrition. In the case of the children, high prevalence rates of stunting (Height/Age < -2 Zscores) were observed, as indicated in table 3. Chronic undernutrition is caused by extreme poverty,

Table 3. *National Prevalence of Stunting (%) among Children under 5 years old.*

Country	Year of survey	Prevalence rate	Prevalence rate among the age group of 24-36 months
Burkina Faso	1992-1993	33.3	40
Cape Verde	1993	15.3	–
Mali	1995-1996	30	47
Mauritania	1998	34	–
Niger	1992	39.5	47
Senegal	1992-1993	22	29

Source: DHS.

seasonal drought and conflict, diet quality and quantity, marginal access to food and inadequate access to health services, education and a heathy environment (Waterlow, 1985). In the Sahel, this should be considered a dominant factor with regard to the food and food security of the population.

POPULATION GROWTH AND FOOD SUPPLY AND DEMAND

Population growth remains the most predictable fact in the long-term. As for all the Sahelian countries, the "Study on Long Term Perspectives" in Western Africa conducted by the Club du Sahel shows a yearly population increase around 2.7% for the period 1960-1990. It is now estimated that the twenty-million Sahelian population in 1960 will have undergone a 4.5 fold increase by the year 2020 and will reach approximately 100 million by the years 2025-30. The mean synthetic fertility rate is about 6.5 children per woman in the Sahel. The rate is 6.6 in Chad (DHS, 1996-97), 6.9 in Burkina Faso (DHS, 1993), 7.4 in Niger (DHS, 1992), 6.7 in Mali (DHS, 1995-96), and 6 in Senegal (DHS, 1992-93). Although a slight decrease in fertility can be foreseen as a result of better town planning and education, the natural population increase will be strongly related to the younger population's procreation levels. According to Bos *et al.*, 1994, the projected changes in age patterns in the developing countries by 2025 will lead to a pyramid structure.

Urbanisation, which is a real phenomenon, will continue. According to the data of the Club du Sahel and the CILSS/CERPOD, the rural and urban population ratio, which is now 70/30 will reach 66/34 or 55/45 in the year 2020 (CILSS, 1998). Hence access to food and nutritional security will not only depend on population growth but also on population distribution, and whether the urban component will get enough resources to meet its food needs. Regulating population growth and distribution will be the hardest task facing the Sahelian region in the future.

The Sahelian region remains an agricultural and cereal-growing space. Consequently, meeting the food demand depends largely on agropastoral performance (agriculture, cattle breeding, fishing and market gardening). Currently, the Sahelian countries are undergoing a period of chronic food deficit. Sahelian dependence on cereal importation ranges from 15 to 20%, as shown in table 4 which refers to the period 1990-1997. At national levels, situations are different: Burkina Faso, Chad, Mali, and the Niger, which represent three quarters of the Sahelian population, provide 85% of cereal production (table 1). Consequently, the evolution of production with regard to population growth varies considerably from one country to another (CILSS, 1998). Urbanisation accelerates dietary transition, thus fruit and livestock products are progressively becoming a part of the Sahelian diet, in proportion to income and price elasticity. However, the increase of market garden production is mainly devoted to exports. The traditional transhu-

Table 4. *Structural Evolution of Cereal Resources (%) in the Sahel from 1990 to 1997.*

Year	Production	Stocks	Importation
1989/90	69.8	16.8	13.4
1990/91	64.5	10.1	25.4
1991/92	77.2	6.1	16.7
1992/93	75.8	10.3	13.9
1993/94	79.0	8.0	13.0
1994/95	81.0	6.0	13.0
1995/96	76.0	8.0	16.0
1996/97	73.0	8.0	19.0

Source: CILSS/DIAPER.

mance of cattle tending has been sedentarised, leading to an increase in environmental degradation and making the local market incapable of competing with the European countries in terms of meat importation. Fishery resources are important thanks to the presence of lakes, streams and seas in certain countries (Senegal, Cape Verde, Mauritania, Bissau Guinea). However, local consumption varies considerably due to inequality in fish distribution (urban versus rural) and enclavement. In the local markets of large towns there is price inflation, especially due to fish exports to Europe (in Senegal, fishing activities generate more currency than agricultural exports), making it impossible for the major part of the population to meet their needs in protein consumption (CILSS, Sahel 21, 1997).

No forecast is planned for the future but if the constraints on the environment persist, food dependency *vis à vis* foreign countries will increase. Thus, the Sahel will be one of the regions in which food security will be hard to achieve. In addition, this strong dependency on foreign countries (importation, food aid) is helping to modify dietary habits, especially in the urban areas, and consequently will lead to other forms of malnutrition.

CONSTRAINTS RELATED TO LACK OF NATURAL RESOURCES, THE ENVIRONMENT AND HUMAN RESOURCES

The Sahelian economies are structurally dependent on agriculture which in turn is strongly dependent on natural resources. Direct food consumption is based on cereals, food crops and livestock, while exports are dominated by cotton, peanuts, halieutic resources and market garden products. In the Sahel, agriculture is mainly rain-fed with irrigated culture accounting for less than 30% of the potential resources, except in the case of Cape Verde and Mauritania (table 5). Moreover, the increase in food production required by the increase in population growth has resulted in an incomplete natural regeneration of the soil and has decreased fertility. Food security in the Sahel in the near future will depend on how the region is able to apply known crop technologies, including high-yielding varieties of seed, fertilisers (specially phosphate rock as a source of phosphorus fertiliser), and irrigation. Some countries in the Sahel are particularly rich in phosphate rock deposits. The total reserves and resources in Senegal and Burkina Faso are estimated to be 3100 and 1500 million tons respectively (Hammond *et al.*, 1986).

There is also considerable water potential. Dense natural water sources can be found: Senegal 1700 km; Gambia 1130 km; Chari 1200 km; Volta 1200 km; Niger 4200 km; and Lake Chad has an area of 25000 km^2. But despite this important water potential, access to drinking water, which constitutes an important part of food security, is far from being systematic (table 6).

Table 5. *Potential and Actual Land Planning for Irrigated Culture in the Sahel.*

Country	Potential land for irrigation (1000 ha)	Irrigated land (1000 ha)	Irrigated land (%)
Bissau Guinea	281	42	15
Burkina Faso	164	46	28
Cape Verde	3	2.8	93
Chad	935	113	12
Mali	560	200	36
Mauritania	221	113	51
Niger	270	78	29
Senegal	400	141	35
The Gambia	80	15	18
CILSS	**2914**	**751**	**25**

Source: FAO.

Table 6. *Part of Population Having Access to Drinking Water in some Sahelian Countries.*

Country	% of total population	% in the urban area	% in the rural area
Bissau Guinea	53	38	57
Chad	24	48	17
Mali	37	36	38
Niger	54	46	55
Senegal	52	85	28
The Gambia	48	67	–

Source: UNICEF, 1996. Period 1990-1995 – *State of the World's Children.*

Currently, farming is the major activity of the working population. However, the Sahel is undergoing important and rapid urbanisation which will reverse the rural to urban ratio in the future. In these conditions, food security problems will not be only a question of production but a matter of access and food supply, particularly in the urban areas.

Access to domestic energy constitutes another obstacle to the achievement of food and nutritional security in the Sahel. The high consumption of charcoal is a serious threat to the environment both now and in the future. In Senegal, 60% of national energy use still comes from charcoal despite the considerable progress in gas use (CILSS, 1977).

In all the Sahelian countries women constitute the majority of the population. They are the main actors as regards family food and nutritional security. They play a very important role in farming activities, food transformation and commercialisation, water supply and the provision of domestic fuel (ORSTOM-CIE, 1985). Women are, and will be more and more, involved in initiating the most decisive transformations in food and nutritional security in the future. The correlation between female literacy, decreased fertility, child survival and the improved nutritional status of families has been clearly revealed in all the DHS surveys in the Sahel. Despite this fact, maternal mortality is still high. 652 per 100,000 live births in Niger; 577 in Mali; and 555 in Senegal. Education levels among women is very low: 70% of women are without education in Mauritania; 89% in Mali; 54% in Burkina Faso; 92% in Chad; and 67% in Senegal (CILSS, Sahel 21, 1997). For this reason, the condition of women is one of the major problems faced by Sahelian countries. The key to future food and nutrition security in the Sahel will also depend on attempts to improve women's conditions, especially with regard to education, health and nutrition.

Regional Co-operation and Policy Implications in the Near Future

The Sahelian community, which was born as a strictly political framework, seems to be becoming more and more involved in a process of building a stronger union which will lead to West African integration (Sahel 21, Bilan et Perspective). The West Africa Monetary and Economic Union (UEMOA), which includes Benin, Burkina Faso, Ivory Coast, Mali, Niger, Senegal, Togo and Bissau Guinea, seems to be the logical process for the economic and monetary integration of all these countries of the Sahel. The goal of such a project will be the creation of a common market on the European Union model. Like the CILSS, the agricultural policy of the UEMOA is presented as being one of the vehicles to develop the sub-region to achieve food security. It is clear that concerted action and joint efforts will be required to meet the future food needs of the sub-region. The noble objectives of the UEMOA should be translated into concrete actions to alleviate poverty, malnutrition and food insecurity.

Currently, in all the Sahelian countries, the national development policies (including agriculture) are essentially based upon Structural Adjustment Programmes (SAP) imposed by the Breton Woods institutions (the IMF, the World Bank). These programmes are characterised by similarity and do not take into account the specific realities of each country and are erroneous in their calculation of economic sustainability. The social impact of these programmes is for the moment catastrophic for all the Sahelian countries, which rank far behind, among the poorest on the earth, according to the Human Development Index (PNUD, 1998). Despite the claimed improvement in economic conditions, resulting from structural adjustment and economic reforms, large concentrations of poor people still exist. According to estimates, around 40% of the Sahelian populations suffer from food insecurity, of which 25% from chronic food insecurity caused by extreme poverty (Club du Sahel/CERPOD/CILSS). If the Sahel aim is to eliminate under-development, malnutrition and repeated threats of widespread hunger, the SAPs should be re-examined.

Conclusion

Progress has been made in the Sahel because life expectancy has increased and child mortality shows a steady downward decrease over the last decade. However, the serious problems that will continue to exist in the Sahel with regard to food and nutrition security are the rapid growth in population, the increase in food imports, the absence of cost-effective investment in agriculture, irrigation, water supply, rural infrastructure, and human capital, especially with respect to women. The food gap suggests that chronic undernutrition and periodic famines are likely to continue if agriculture remains rain-fed and if the constraints in relation to agricultural practices, the environment, human resources, and armed conflicts are not overcome. National, regional and international efforts are needed to reverse the deteriorating trends in food supply and demand in Africa.

REFERENCES

ACC/SCN (1997): *Third Report on the World Nutrition Situation.*

Alexandratos, N. (1995): 'The Outlook for World Food and Agriculture to Year 2010', in N. Islam (ed.), *Population and Food in the Early Twenty-First Century: Meeting Future Food Demand of an Increasing Population* (Washington, D.C., International Food Policy Research Institute), pp. 25-60.

Bleiberg, F., Brun, T.A., Goihman, S., and Gouba, E. (1980): 'Duration of Activities and Energy Expenditure of Female Farmers in Dry and Rainy Season in Upper Volta', *British Journal of Nutrition*, 43, pp. 71-81.

Bos, E., Vu, M.T., Massiah, E., and Bulatao, A. (1994): *World Population Projections* (Baltimore, John Hopskins University Press).

Centre régional Agrymet (1998): *Situation Agrométéorologique et Hydrologique dans les Pays du CILSS en 1997 – Synthèse Régionale.*

CILSS (1997): *Sahel 21, Bilan Diagnostic Global et Interrogations sur le Futur* (Praïa, Cap Vert, *document CILSS*).

CILSS (1998): Quelles Stratégies alimentaires pour le Sahel? Nouveaux Défis, Nouvelles Approches des Rôle et Responsabilités des Différents Acteurs, Implications pour les Activités du CILSS, *Document de synthèse.*

Diaham, B., Diallo, A., Lemonnier, D., and Wade, S. (1991): 'Etude de Différentes Préparations Culinaires chez les Wolofs et les Sérères au Sénégal', in D. Lemonnier, Y. Ingenbleek, P. Hennart (eds.), *Alimentation et Nutrition dans les Pays en Développement* (Paris, Karthala - ACCT, AUPELF), pp. 123-131.

Diaham, B., Wade, S., Lemonnier, D., Guiro, A.T., Coward, W.A., Sall, M.G., and Prentice, A. (1997): '24-h Total Energy Expenditure of the West African Farmers during the Wet Season Measured by the Doubly Labelled Water $D^{18}O$', *16th International Congress of Nutrition*, July 27-August 01, Montreal, Canada (PM 142).

FAO/WHO/UNU (1985): 'Energy and Protein Requirements', Report of a joint FAO/WHO/UNU expert consultation, *World Health Organ. Tech. Rep. Ser. 1985*, pp. 724.

Hammond, L.L., Chien, S.H., and Mokwunye, A.U. (1986): 'Agronomic Value of Unacidulated and Partially Acidulated Phosphate Rocks Indigenous to the Tropics', *Advances in Agronomy*, 40, pp. 89-140.

Minghelli, G., Schutz, Y., Charbonnier, A., Whitehead, R., and Jéquier, E. (1990): 'Twenty-four-hour Expenditure and Basal Energy Metabolic Rate Measured in a Whole-body Indirect Calorimeter in Gambian Men', *American Journal of Clinical Nutrition*, 51, pp. 563-570.

Minghelli, G., Schutz, Y., Whitehead, R., and Jéquier, E. (1991): 'Seasonal Change in 24-h and Basal Energy Expenditure in Rural Gambian Men Measured in a Respiratory Chamber', *American Journal of Clinical Nutrition*, 53, pp. 14-20.

ORANA/ORSTOM (1980): 'Etat Nutritionnel de la Population Rurale du Sahel' (Rapport d'un groupe de travail, Paris, ORSTOM).

ORSTOM/CIE (1985): 'Femmes et Politiques Alimentaires', Actes du Séminaire International sur la Place des Femmes dans l'Autosuffisance et les Stratégies Alimentaires (ORSTOM, Paris).

PNUD (1998): Rapport sur le Développement Human.

Singh, J., Prentice, A., Diaz, E., Coward, W.A., Ashford, J., Sawyer, M., and Whitehead, R.G. (1989): 'Energy Expenditure of the Gambian Women During Peak Agricultural Activity Measured by the Doubly Labelled Water Method, *British Journal of Nutrition*, 62, pp. 315-329.

Snrech, M.S. (1997): 'Croissance Démographique et Développement Urbain: Impact sur l'Offre et la Demande Alimentaires, Bilan et Perspectives à long Terme en Afrique de l'Ouest' (*Document Sahel N.CS(97)*, Club du Sahel-OCDE).

Waterlow, J.C. (1992): *Protein Energy Malnutrition* (Edward Arnold, London).

FOOD PRODUCTION AND DEMAND SITUATIONS IN SOUTH ASIA

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I. INTRODUCTION

South Asia, comprising Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka, has high population pressure on land and other resources to meet its food and development needs. These countries, with a total population of about 1291.2 million people in 1998, accounted for 21.8 per cent of the world population but had only 3 per cent of the world land area. Half of the land area of South Asia is under arable and permanent crops, while in the world as a whole only 11 per cent of the total land area is under arable land and permanent crops. During the last three decades, the South Asia region has made remarkable progress in its food and agricultural production. The near famine conditions prevailing in the early 1970s in several pockets of this region have largely been eliminated and the region has not only generally overcome the food crisis but has also advanced from a food deficit to a self-sufficiency status. For instance, foodgrain production in India increased from about 72 million tonnes (mt) in 1965 to 195 mt in 1997-98. Bangladesh, a country which imported annually about 3.5 mt foodgrains in the mid 1960s, became self-sufficient in food grains in 1993 despite a doubling of her population. These changes have been triggered by a Green Revolution in South Asia involving the development and diffusion of high yielding varieties, especially of rice and wheat, from the mid 1960s onwards. This has been accompanied by increased levels of the use of inputs, particularly irrigation, fertilisers and tractors, and policy support. Government investment in infrastructure, research and extension, price and other policies, along with crop, livestock and fisheries production strategies, have significantly helped to increase food production and its availability.

The emerging production scenario, higher economic growth, the population explosion, and shifts in dietary pattern will change the supply and demand prospects for food in the next century. Producing additional food with limited and degraded natural resources and the provision of economic access to food at the household level to ensure food security for all will be the major challenges for these nations. This calls for a review of the current food situation and of future needs in the next century in South Asia. This paper is an attempt to (i) examine the current situation and trends in food production, (ii) project the food consumption pattern and nutritional status of households, (iii) project the demand for foodgrains, livestock, fisheries and horticultural products from 2000 to 2030, and (iv) estimate fix yield and production targets to maintain self-reliance among South Asian countries, and suggest strategies to enhance food production.

II. FOOD PRODUCTION

Agricultural Production and Productivity

Crop production strategies followed during the post-Green Revolution period have significantly helped to increase food production. The current situation and trend in food production based on the data provided in the FAO/RAPA publication is examined. The average production and yield figures are given for the year 1994-96 in tables 1 and 2. The growth analysis by area, production and yield pertaining to the period 1986-96 is presented in table 3. The average annual growth rates in area, production and yield of major cereals for South Asian countries for the periods 1969-78, 1978-87 and 1987-96 are also given in Appendix 1.

Cereals

With an annual production of about 106 mt of rice, South Asia accounts for about 29 per cent of the world's rice production, although its average yield is only 1.87 tonnes per hectare against about 2.5 to 4.7 t/ha in several of the developing countries of the Asia-Pacific region. The gains in rice output have come essentially from the steady increase in yield per unit area in India and Bangladesh. This has come essentially from the better utilisation of the existing infrastructure, a stepping-up of the use of modern inputs, and the extension of the techniques of the Green Revolution to new areas. Yield growth rates of 2.5 and 2.2 per cent in India and Bangladesh were quite satisfactory, but there is space to accelerate the pace in other countries. India and Bangladesh are the major rice producing countries of

Table 1. *Per cent share of country in the production of South Asia, 1994-96.*

Item	Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka	South Asia	
							Prod. (mt)	Share in World (%)
Staple food crops								
Rice	16.37	0.03	76.57	1.98	3.45	1.60	105.7	28.85
Wheat	1.54	0.01	76.85	1.18	20.43	0.00	80.1	14.54
Maize	0.02	0.33	77.70	10.86	10.82	0.26	12.0	2.16
Coarse grains	0.21	0.30	89.11	4.65	5.50	0.11	34.4	3.97
Cereals	8.45	0.09	78.67	2.11	9.95	0.78	220.3	12.35
Pulses	3.27	0.01	90.68	1.14	4.66	0.24	16.4	28.81
Roots & Tubers	6.41	0.19	84.60	3.35	4.96	0.49	29.4	4.72
Horticultural crops								
Vegetables	2.04	0.02	90.05	1.73	5.32	0.85	71.3	12.75
Fruits	3.02	0.14	83.69	1.22	11.44	1.70	45.6	11.32
Other crops								
Edible Oil crops	1.62	0.00	88.16	0.44	7.17	2.60	9.6	10.65
Sugar cane	2.39	0.01	81.60	0.49	15.06	0.45	302.9	26.34
Livestock products								
Milk	2.25	0.04	74.76	1.16	21.44	0.34	84.0	15.69
Meat	5.48	0.12	63.94	2.66	26.51	1.29	6.5	3.15
Eggs	4.17	0.01	78.00	0.98	14.21	2.62	1.9	4.37
Fisheries products								
Fish	16.58	0.00	71.10	0.28	8.59	3.44	6.7	6.11

Table 2. *Average yield (tonnes per ha) for staple food and other crops in South Asia, 1994-96.*

Item	Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka	South Asia	World Average
Rice	1.74	1.11	1.92	1.46	1.70	1.96	1.87	2.47
Wheat	1.88	0.80	2.45	1.49	2.00	–	2.31	2.48
Maize	0.89	0.99	1.52	1.67	1.46	1.04	1.53	4.01
Coarse grains	0.73	1.22	0.95	1.51	1.00	0.94	0.97	2.63
All cereals	1.74	1.08	1.74	1.49	1.79	1.91	1.74	2.55
Pulses	0.75	1.00	0.60	0.61	0.50	0.77	0.60	0.81
Roots & Tubers	10.64	10.75	16.95	7.70	14.23	8.90	14.60	12.75
Sugarcane	40.58	31.22	67.36	35.53	46.62	58.59	61.3	62.12

Table 3. *Average annual compound growth rate (per cent) in area, production a yield for various food commodities in South Asia 1986-96.*

Item	Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka	South Asia	Worl
Staple food crops								
Rice								
Area	–0.6	–1.3	0.5	0.0	0.9	1.3	0.3	0.4
Prod.	1.6	–1.9	3.0	1.0	1.5	–0.5	2.7	1.8
Yield	2.2	–0.6	2.5	1.0	0.6	–1.8	2.4	1.4
Wheat								
Area	1.8	–3.5	1.1	1.2	1.2	–	1.0	–0.1
Prod.	2.4	–4.2	3.7	3.0	3.0	–	3.4	0.9
Yield	0.6	–0.6	2.6	1.8	1.8	–	2.4	1.0
Maize								
Area	–0.5	–1.0	0.3	0.5	0.6	–0.5	0.2	0.7
Prod.	–1.9	–2.7	2.3	2.6	1.5	–2.4	1.9	2.4
Yield	–1.4	–1.7	2.0	2.1	0.9	–1.9	1.7	1.7
Cereals								
Area	–0.5	–1.0	–0.4	0.6	0.9	1.1	–0.3	–0.1
Prod.	1.6	–2.0	2.9	1.8	2.5	–0.6	2.8	1.1
Yield	2.2	–1.0	3.2	1.2	1.6	–1.7	3.1	1.3
Pulses								
Area	–0.3	–7.2	0.8	2.2	0.9	–2.6	0.7	0.3
Prod.	0.2	–4.3	2.2	2.7	0.5	–3.2	1.6	0.7
Yield	0.5	1.6	1.3	0.5	–0.5	–0.4	0.9	0.3
Roots and Tubers								
Area	1.0	–3.2	1.6	2.7	3.1	–4.2	1.8	1.1
Prod.	1.4	0.8	3.5	5.9	6.5	–4.8	4.0	1.3
Yield	0.4	3.3	1.9	3.1	3.2	–0.5	2.2	0.2
Other crops								
Sugarcane								
Area	1.0	0.3	2.4	6.5	2.4	1.3	2.5	1.7
Prod.	0.8	1.0	3.8	10.4	4.9	6.7	4.0	2.2
Yield	–0.2	0.7	1.3	3.9	2.4	5.3	1.5	0.4
Edible oil crops production (oil equivallent)								
Edible oil	0.9	–	6.2	2.0	2.0	0.3	5.0	3.7
Horticultural crops production								
Vegetables	2.5	0.7	2.2	5.2	5.1	–0.1	2.8	2.9
Fruits	0.3	3.6	4.7	4.8	4.6	–0.4	4.5	2.2
Livestock products								
Milk	4.1	0.4	3.3	–1.8	2.4	5.4	3.4	0.2
Meat (Slaughtered)	3.6	1.7	3.1	1.8	6.3	7.1	3.3	2.9
Hen eggs	6.9	4.0	5.2	4.5	6.0	1.7	5.4	3.2
Fish	7.0	0.0	4.9	7.9	1.2	4.3	5.2	3.7

Source: FAO, RAPA Publication: 1997/23.

the South Asia region, contributing 77 per cent and 16 per cent respectively.

With an annual production of about 80 mt, the region accounted for about 14.5 per cent of the world's wheat production. India and Pakistan are the major wheat producing countries in the region, contributing 77 per cent and 20 per cent respectively. The production in these two countries during the last ten years has witnessed more than an 3 per cent annual growth rate, involving both yield and area growth. Bangladesh started wheat production about 25 years ago and now produces about 1.2 mt. Nepal is historically a wheat growing country, responsible for about 1.2 per cent of the production of the region and its production is increasing steadily at an annual growth rate of 3 per cent. Bhutan is a marginal producer and its production has declined in the last ten years. Sri Lanka does not produce wheat.

South Asia's share in world maize production is only 2.2 per cent, with about 12 mt of annual production. India accounts for about 78 per cent of the region's maize production and Nepal and Pakistan for 11 per cent each. Maize yields in this region are generally low, ranging between 0.89 tonnes to 1.67 tonnes per hectare against a world average of 4.0 tonnes. India and Nepal recorded yield growth rates of about 2 per cent per year 1986-96. In Bangladesh, Sri Lanka and Bhutan, maize production declined due to a fall in area and yield over the last ten years. In Nepal, India and Pakistan production increased annually by 2.6 per cent, 2.3 per cent and 1.5 per cent, respectively, due to positive growth in area and per hectare yield.

A declining trend in area growth was observed for rice wheat and other cereals. However, the increasing trend in production was because of yield growth (Appendix 1). Future growth in cereal production will have to be achieved principally from yield growth.

South Asian cereals account for about 12.4 per cent of total world cereal production. India accounts for about 79 per cent of the region's cereal production, followed by Pakistan (10 per cent), Bangladesh (8 per cent) and other South Asian countries (3 per cent). Average cereal yield in the region was 1.7 tonnes per hectare against 2.6 tonnes for the world as a whole. Sri Lanka recorded the highest average yield of about 1.9 tonnes per hectare, followed by 1.8 tonnes in Pakistan, 1.7 tonnes in Bangladesh and India, and less than 1.5 tonnes in the remaining countries. The yield growth rate in the region, at 3.1 per cent, was more than double that of the world's growth rate (1.3 per cent). Despite its large area, India scored the highest growth rate in cereal production (2.9 per cent) followed by 2.5 per cent in Pakistan, 1.8 per cent in Nepal, and 1.6 per cent in Bangladesh, whereas Bhutan and Sri Lanka registered negative growth rates. The share of rice in the total cereal production was 48 per cent, followed by wheat (36 per cent) and coarse grains (15 per cent). Maize accounted for one-third of the total coarse grain production, and is gaining importance as feed.

Pulses

South Asia, with an annual production of 16.4 mt, accounted for about 29 per cent of the world's pulse production while its share of world area has been 40 per cent in the recent past. The average yield was only 600 kg per hectare against 847 kg per hectare at the world level. India accounted for 91 per cent of the region's pulse production. During the decade ending 1996, India registered a yield growth of 1.2 per cent *per annum* while for the other major countries yield gains were generally low and in Pakistan it was even negative.

Roots and Tubers

South Asia produces over 29 mt of roots and tubers, mainly potatoes, accounted for about 4.7 per cent of the world's production, and registered an average yield of about 14.6 tonnes per hectare against about 12.8 tonnes for the world as a whole. India's share in the region's production was 82 per cent and its yield of 17 tonnes per hectare was one of the highest in the whole of Pacific Asia. The increase in production accrued through an increase in area as well as yield in all the major countries.

Sugarcane

With an annual production of 303 mt, South Asia is responsible for 26 per cent of the world's sugarcane production. India and Pakistan are the major sugarcane producers in the region with 82 and 15 per cent of South Asian production respectively. India's average yield of about 67 tonnes per hectare, which is the highest in the region, exceeded the world average by about 5 tonnes per hectare. Yield levels in other South Asian countries are rather low. In 1986-96, sugarcane production in the region showed an increase of 4 per cent *per annum*.

Oil Crops

Measured in terms of oil equivalent, South Asia, with an annual production of 9.6 mt, accounts for 11 per cent of the world's vegetable oil production. India accounted for 88 per cent of regional production, and has achieved a very high growth rate, exceeding 6 per cent *per annum* in 1986-96. The breakthrough in Indian oilseed production occurred due to a synergistic interplay of appropriate technologies, development and institutional support, and marketing and price support through a mission mode project.

Horticultural Crops

Having achieved a significant increase in the production of cereals, oil seeds, and other food crops, the countries of the region, and especially India and Pakistan, have in recent years started paying much greater attention to horticultural crops. South Asia produced about 46 mt of fruit (excluding melons), which was about 11 per cent of the world's production. India accounted for about 84 per cent of the region's fruit production, followed by Pakistan (11 per cent), Bangladesh (3 per cent) and the small share of other countries. India and Pakistan, the major producers, achieved impressive growth rates of about 4.5 per cent *per annum*. Banana, citrus and mango are predominant fruits in the region, with about 18 per cent, 15 per cent and 23 per cent share of total fruit production respectively.

South Asian countries, with an annual production of about 71 mt of vegetables, accounted for about 13 per cent of the world production of vegetables (including melons). India accounted for 90 per cent of the total regional production, showing an annual growth of 2.2 per cent at this high base level. All countries with the exception of Sri Lanka witnessed a considerable increase in vegetable production, and the rate of growth for the decade ending 1996 was 0.7 per cent in Bhutan, 2.2 per cent in India, 2.5 per cent in Bangladesh, 5.1 per cent in Pakistan, and 5.2 per cent in Nepal.

Livestock and Fisheries Production

With an annual production of only 6.5 mt of total meat, 1.9 mt of eggs, 6.7 mt of total fish, the share of the region in world production of these foods has been rather small, being 3.2 per cent, 4.4 per cent and 6.1 per cent, respectively. This region's share of world milk production is quite high (15.7 per cent), with an annual production over 84 mt. The average rate of growth of production of various products during the decade 1986-96 in the South Asian countries was 3.4 per cent for milk, 3.3 per cent for meat, 5.4 per cent for eggs (hens) and 5.2 per cent for fish. These rates generally far exceed the corresponding rates of growth at a world level. India, Pakistan and Bangladesh are the major producers of livestock and fisheries products in South Asia. India's share in South Asian production ranged between 64 to 78 per cent (the minimum for meat and the maximum for eggs). Pakistan accounted for 21 per cent of milk, 27 per cent of meat and only 9 per cent of fish, and Bangladesh for 2.2 per cent of milk, 4.2 per cent of eggs, 5.5 per cent of meat, and 16.6 per cent of fish, in terms of South Asian production.

III. DEMAND FOR FOOD

The conditions concerning food, agriculture, and the environment in South Asia appear to be improving. Foodgrain production has been growing faster than the population. This is true for India, Pakistan and Bangladesh. The *per capita* availability of foodgrains in the region, except pulses, is rising. Because of the increasing availability of a wide variety of food items and the increase in *per capita* income and urbanisation, the demand for better quality and nutritional food is now greater than in the past. This has led to changes in the composition of the food basket, with consumers moving from coarse grains to superior grains (rice and wheat), and from grains to livestock and horticultural products (milk, meat, vegetable, fruits, etc.). These structural changes have brought about major shifts in favour of the consumption of milk, fruits and vegetables (Appendix 2). This has significant implications for food demand, research priority setting, and resource allocation in relation to food security. Diversification into the production of livestock, fisheries and horticultural products needs to be the current research priority, backed up by additional resource support.

Demand Elasticity

Demand elasticities are crucial parameters in food demand projections. The elasticities based on food characteristic demand systems (Bouis, 1992) are given in table 4. The expenditure elasticities are in accordance with *a priori* expectations. The magnitude of expenditure elasticity for each food item across countries varies within a narrow range. The expenditure elasticity for all food items except cereals is found to be positive and significantly high in magnitude. Expenditure elasticities for cereals are negative and highly inelastic. The results follow the historical trend in *per capita* consumption of cereals as observed in the household consumer survey data available for various South Asian countries. The commodities with the cheapest source of calories have the lowest income elasticities. The magnitude of food demand elasticity is about 0.4, while the calorie-income elasticities were not significantly different from zero because of structural shifts in dietary patterns from low-cost calorie food to high-cost calorie food items. This observation confirms the empirical evidence presented by Behrman and Deolalikar

Table 4. *Expenditure elasticities based on FCDS.*

Food items	Bangladesh	India	Nepal	Pakistan	Sri Lanka
Rice	–0.078	–0.016	0.016	0.025	–0.071
Wheat	0.004	–0.109	–0.111	–0.121	–0.027
Coarse grains	–0.129	–0.147	–0.152	–0.172	–0.170
Roots & Tubers	0.250	0.336	0.300	0.282	0.371
Pulses	0.227	0.214	0.263	0.189	0.224
Vegetable oils	0.191	0.176	0.199	0.186	0.128
Sweeteners	0.116	0.115	0.107	0.094	0.097
Vegetables	0.500	0.673	0.599	0.565	0.748
Fruits	0.666	0.702	0.698	0.710	0.556
Milk	0.581	0.589	0.634	0.575	0.689
Meat, fish & eggs	0.822	0.892	0.860	0.670	0.866
Other food	1.139	1.200	1.177	1.242	1.196
Non-food	1.883	1.959	1.919	2.052	1.977
Income elasticities of					
Calories	0.044	0.050	0.048	0.047	0.058
Food	0.448	0.399	0.424	0.342	0.402

FCDS: Food Characteristic Demand System (Bouis, 1992).
Sources of data: Bangladesh Bureau of Statistics, Report on the household expenditure survey 1988-89.
Household income and expenditure survey, Federal Bureau of Statistics, Islamabad.
Household Expenditure consumer survey data, 50th National Sample Survey round, CSO, India.
For Nepal and Sri Lanka data, FAOSTAT.

(1989) for India and by Bouis and Haddad (1992) for the Philippines. Thus the demand elasticities estimated in this study are likely to give the most reliable demand projections for cereals and other food commodities.

Future Consumption Pattern

Expenditure elasticities are used to project the annual *per capita* consumption for each South Asian country under the alternative scenarios of 3.5 per cent and 5.5 per cent growth in *per capita* gross domestic product (PCGDP) under the alternative assumptions that the magnitude of expenditure elasticities as observed in 1993 will decline to a level of 75 per cent, 50 per cent, and 25 per cent by 2025. Historically, the first scenario is the most plausible rate and the second scenario is considered to be the most likely in the long term. The prediction for *per capita* consumption of food becomes asymptotic to the year axis in the long term under the assumption of a 50 per cent decline in elasticities. In reality, it is expected that the consumption level of food items in the long run will stabilise, income elasticity for food will converge to zero, and that the income effect on *per capita* consumption will be negligible. A fifty per cent decline in expenditure elasticities by 2025 is considered the most likely scenario to explain consumption behaviour in the long term. The average annual *per capita* availability of different commodities for 1992-94 (given in Appendix 3) is used as the base consumption for predicting the dietary pattern of the years 2000 to 2030 (Appendices 4 and 5).

Rice is the staple food of Bangladesh, wheat of Pakistan, rice and wheat of India and Sri Lanka, and rice, coarse grains and wheat of Nepal. The *per capita* consumption of edible oils is highest in Pakistan (14 kg per year), compared to other countries where it ranges from 2.3 kg in Sri Lanka to 8 kg in India. Pakistan also dominates the consumption of sugar, milk and meat. India dominates in the consumption of vegetables and sugar. Bangladesh and Sri Lanka dominate fish consumption. A wide variation in the consumption of various foods is observed across the countries. This is because the dietary pattern of a country is highly influenced by its domestic production patterns and food availability.

Expenditure Growth Effects on Consumption

The expenditure growth effects on dietary pattern at constant prices are shown in table 5. The income effect on consumption is negative and mild for cereals and is positive and significant for livestock, horticultural and fishery products. South Asia will continue to exhibit a more diversified food basket with significantly higher levels of *per capita* consumption of milk, fruits, vegetables, meat, eggs and fish. The increasing trends in consumption towards high value commodities will generate a high growth in demand for pulses, livestock, fisheries and horticultural products.

The impact of structural shifts in dietary patterns on nutrition in terms of energy, as expected, has shown a marginal improvement (table 6). The average daily calorie intake varied from 2017 calories in Sri Lanka to 2347 calories in Pakistan in 1995, which will improve by the year 2030 to a calorie level of 2059 in Bangladesh, 2151 in Sri Lanka, 2235 in Nepal, 2389 in India and 2554 in Pakistan. These calorie levels are higher than those recommended for each of the South Asian countries. In spite of a shift in diet from cereals to non-cereals, foodgrains will continue to dominate and maintain their share of 62-65 per cent in total energy. In spite of steady growth in the consumption of horticultural, livestock and fishery products, and other food items, their share in total energy will only improve from 5.2 per

Table 5. *Annual per capita food consumption (Kg) in South Asia during the year 2000.*

Food	Low income growth			High income growth		
	2000	2030	Changes	2000	2030	Changes
Cereals	158.2	154.0	–4.2	156.8	150.3	–6.5
Pulses	11.1	11.7	+0.6	11.4	12.5	+1.1
Roots & Tubers	19.9	21.5	+1.6	20.5	23.6	+3.1
Edible oils	7.6	8.3	+0.7	7.8	8.8	+1.0
Sugar	22.4	23.2	+0.8	22.7	24.1	+1.4
Vegetables	62.2	79.2	+17.0	67.9	101.1	+33.2
Fruits	38.5	49.7	+11.2	41.8	62.6	+20.8
Milk	65.4	83.2	+17.8	70.1	100.8	+30.7
Meat	6.2	8.8	+2.2	6.8	11.4	+4.6
Eggs	1.6	2.2	+0.6	1.8	2.9	+1.1
Fish	5.3	7.1	+1.8	5.8	9.4	+3.6

Low income growth: 3.5 per cent GDP growth.
High income growth: 5.5 per cent GDP growth.

Table 6. *Demand for energy from major food groups as percentage of total dietary energy demand.*

Food group	Year	*Per capita* GDP	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Food grains	1995	3.5%	85.9	68.6	81.9	61.0	75.8	69.8
	2030	3.5%	83.2	64.0	77.6	55.5	71.4	65.0
	2030	5.5%	81.2	60.6	74.3	51.7	68.1	61.7
Horticultural product	1995	3.5%	2.4	5.8	5.9	3.4	6.3	5.2
	2030	3.5%	3.0	7.6	7.2	4.4	7.9	6.7
	2030	3.5%	3.4	8.9	8.3	5.1	9.1	7.8
Livestock and fisheries products	1995	3.5%	3.0	7.3	6.5	13.0	5.7	7.5
	2030	3.5%	4.4	9.8	9.1	16.8	8.2	10.3
	2030	3.5%	5.5	11.7	11.1	19.7	10.2	12.3
Other food items	1995	3.5%	8.7	18.2	5.7	22.7	12.2	17.5
	2030	3.5%	9.4	18.6	6.1	23.3	12.5	18.0
	2030	3.5%	9.8	18.8	6.8	23.5	12.5	18.3
Daily *per capita* energy in Kcal	1995	3.5%	2048	2188	2107	2347	2017	2188
	2030	3.5%	2048	2294	2172	2455	2086	2289
	2030	3.5%	2059	2389	2235	2554	2151	2375

cent in 1995 to 7-8 per cent in 2030 for horticultural products, from 7.5 per cent in 1995 to 10-12 per cent in 2030 for livestock and fishery products, while there will be a marginal improvement for other food items. This pattern is true for each South Asian country. The importance of cereals and pulses will not decline in the future in meeting nutritional requirements. Thus there is no scope for complacency for any nation and these countries must refrain from diluting their efforts to increase foodgrain production and the production of non-cereal food items.

Population Projections

In the region as a whole, the population growth rate has shown a decreasing trend. Each country is at a different stage of demographic transition. Sri Lanka's birth rate has almost declined to a point where it is only just replacing the present population, and India and Bangladesh are at the point where both the fertility and mortality rates are beginning to decline. Nepal and Pakistan still have high population growth rates. According to the United Nations Population Fund (UNFPA, 1998), the population growth during 1995-2000 will be 1.6 per cent for India and Bangladesh, 2.8 per cent for Bhutan, 2.5 per cent for Nepal, 2.7 per cent for Pakistan, and 1 per cent for Sri Lanka. The population of South Asia is estimated at 1291.2 millions in 1998 and it is projected to reach 1847.2 millions by 2025. Using the predicted population growth for the years 1995-2000 and 1998-2025, the population for each country is predicted for specific years during the period 1995-2030 and these predictions are presented in Appendix 6. These population figures are used in projecting the demand for food. Population growth, which is estimated at 1.73 per cent for South Asia for the years 1995-2000, will decline to 1.55 per cent during the period 2000 to 2010, 1.21 per cent during 2010-2020, and 0.94 per cent during the subsequent decade. The population of South Asia, which was 1226.3 millions in 1995, will increase to 1929.9 millions by the year 2030. India is the most populous country in South Asia, accounting for 76 per cent of the total population in 1995, and will decline to 71 per cent in the year 2030. The population shares of Pakistan, Bangladesh, Nepal and Bhutan in South Asia show an increasing trend due to a higher population growth rate.

Household Demand for Food

Food demand for human consumption is arrived at by multiplying the projected *per capita* consumption by the projected population. The results of human food demand predictions corresponding to the scenario of low and high *per capita* GDP growth at constant prices are given in Appendix 7 and 8. The household demand for foodgrains in South Asia is projected to grow annually by 1.2 per cent and increase from 210 mt in 1995 to 321 mt by 2030, with a break-down of about 145-146 mt for rice, 110-114 mt for wheat, 13-14 mt for maize, 22-24 mt for other coarse grains (sorghum, pearl millet, barley, etc.) and 24-25 mt for pulses (table 7). The demand for roots and tubers, mainly potatoes, and edible oils will be 42-46 mt and 16-17 mt respectively by 2030. Demand by the year 2030 for horticultural, livestock and fishery products will grow three to four times from the level of the year 1995 and will attain the maximum level of 161-195 mt for milk, 153-195 mt for vegetables, 96-121 mt for fruit, 45-46 mt for sweeteners, mainly sugar, 17-22 mt for meat, 14-18 mt for fish, and 4.2-5.6 mt for eggs. India predominates in the food demand in South Asia and accounts for a higher share than its population share (71 per cent) for maize (75 per cent), pulses (91 per cent), potatoes (80 per cent), vegetables (90 per cent), fruit (77 per cent), sugar (78 per cent) and eggs (75 per cent). India's share of demand is lower than its population share for wheat (63 per cent), edible oils (67 per cent), milk (69 per cent), animal fats (64 per cent), meat (61 per cent), and fish (69 per cent). Pakistan accounted for a very high share in demand as compared to its population share (15 per cent) for wheat (31 per cent), edible oils (25 per cent), milk (26 per cent), meat (29 per cent), fruit (17 per cent), sugar (17 per cent), and eggs (16 per cent). Except for rice and fish, the share of Bangladesh's demand in South Asia is lower than its population share (10 per cent). More than 90 per cent of food demand in South Asia will be governed by Bangladesh and India for rice and fish, and India and Pakistan for wheat, edible oil, fruit, sugar, milk, meat, and eggs. India alone will account for a little more than 90 per cent of South Asia's demand for pulses and fruits. As India accounts for the largest share in total food production and consumption in the South Asian region, any change in the surplus/deficit status of India in relation to food production will have significant implications for South Asia's food security and trade.

Domestic Demand Projections

Apart from the demand for direct human consumption, an increasingly important component is the indirect demand for seed, feed, industrial uses and wastage. FAO estimates of other uses, 1992-94 averages, given in Appendix 9, and human demand, are used to estimate the domestic food demand for South Asian countries. Domestic demand projections for food corresponding to low (3.5 per cent) and high (5.5 per cent) *per capita* GDP growth are presented in tables 8 and 9 respectively. The annual growth rates in food

Table 7. *Per cent share of food demand by country in total human demand for South Asia in 2030.*

Food item	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia Demand (mt)
Low growth in Income (3.5% *per capita* GDP growth)						
Rice	20.5	70.3	2.8	3.6	1.7	146.1
Wheat	3.3	63.2	1.2	30.2	1.0	113.5
Maize	0	74.9	14.0	10.2	0.4	14.1
Other coarse grains	0	94	2.2	3.4	0.1	23.5
Total cereals	11.3	70.0	2.7	14.3	1.2	297.2
Total Pulses	4.3	86.7	1.6	6.3	0.6	23.5
Total foodgrains	10.8	71.2	2.6	13.7	1.2	320.7
Potato	7.6	72.7	4.2	7.0	0.3	28.5
Other R&T	5.4	82.3	2.1	6.7	3.0	13.1
Total R&T	6.9	80.5	4.0	6.9	1.2	41.5
Edible oils	5.5	67.0	1.1	25.5	0.3	16.1
Vegetables	1.6	89.6	2.1	5.5	0.7	152.9
Fruits	3.4	76.5	1.5	17.0	1.2	96.0
Sweeteners	3.3	77.8	0.2	17.2	1.1	44.8
Milk	2.3	69.4	1.4	25.9	0.6	160.5
Animal fats	1.2	64.3	1.8	32.0	0.3	4.2
Meat	5.4	59.8	3.5	30.3	0.6	16.9
Eggs	5.3	73.7	1.5	16.6	2.4	4.2
Fish	18.9	68.6	0.4	7.1	4.7	13.7
High growth in Income (5.5% *per capita* GDP growth)						
Rice	20.0	71.1	2.9	3.7	1.8	144.8
Wheat	3.5	63.0	1.2	30.7	1.0	109.5
Maize	0	75.0	14.0	10.0	0.4	13.4
Other coarse grains	0	94	2.2	3.4	0.1	22.3
Total cereals	11.3	70.0	2.7	14.3	1.3	290.1
Total Pulses	4.3	86.7	1.7	6.3	0.6	25.2
Total foodgrains	10.8	71.8	2.6	13.5	1.2	315.3
Potato	7.4	80.0	4.9	6.9	0.3	31.7
Other R&T	5.4	82.4	2.1	6.7	3.0	13.8
Total R&T	6.8	80.8	4.0	6.8	1.1	45.5
Edible oils	5.5	67.0	1.2	25.5	0.3	17.1
Vegetables	1.5	90.2	2.0	5.2	0.7	195.1
Fruits	3.3	76.5	1.5	17.0	1.2	120.7
Sweeteners	3.3	77.9	0.2	17.1	1.1	46.4
Milk	2.3	69.5	1.4	25.8	0.6	194.5
Animal fats	1.2	64.4	1.8	31.8	0.3	5.1
Meat	5.4	61.2	3.5	28.8	0.6	22.1
Eggs	5.2	74.7	1.5	15.7	2.4	5.6
Fish	18.6	69.2	0.4	6.6	4.7	18.2

R&T: Roots and tubers. mt: Million tonnes.

Table 8. *Projected demand for food in thousands of tonnes in South Asia with low growth in per capita income.*

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Rice						
1995	20998	78154	2402	2784	2130	106620
2000	22480	84417	2724	3193	2216	115204
2015	27360	101886	3807	4582	2513	140395
2030	32478	114499	4942	6042	2858	161149
Wheat						
1995	2536	59462	877	19091	860	82944
2000	2747	63375	977	21444	900	89578
2015	3418	74607	1319	29590	1033	110161
2030	4092	83045	1690	38437	1180	128708
Maize						
1995	0	9873	1279	1275	67	12512
2000	0	10466	1415	1422	69	13392
2015	0	12196	1891	1936	76	16127
2030	0	13522	2413	2501	85	18560
Other coarse grains						
1995	0	20569	337	719	17	21674
2000	0	21803	373	802	18	23030
2015	0	25407	499	1091	20	27064
2030	0	28171	636	1410	22	30301
Total cereals						
1995	23535	168058	4895	23869	3074	223750
2000	25227	180061	5490	26861	3203	241204
2015	30778	214096	7516	37199	3641	293747
2030	36570	239238	9681	48390	4145	338718
Pulses						
1995	611	14869	189	857	104	16655
2000	684	16599	222	1006	113	18652
2015	903	21303	332	1508	139	24228
2030	1106	24515	442	2023	163	28306
Foodgrains						
1995	24146	182928	5085	24726	3179	240405
2000	25911	196659	5712	27867	3316	259856
2015	31681	235399	7848	38707	3780	317975
2030	37676	263752	10123	50413	4308	367024

Table 8. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Potato						
1995	1477	17523	812	989	87	20918
2000	1657	19905	959	1177	96	23831
2015	2202	26394	1446	1809	123	32031
2030	2704	30760	1932	2450	147	38070
Other roots and tubers						
1995	505	8350	167	445	375	9856
2000	557	9260	194	519	405	10951
2015	716	11740	280	767	492	14021
2030	867	13447	369	1024	575	16316
Roots and tubers						
1995	1982	25873	980	1434	462	30775
2000	2214	29165	1153	1696	501	34781
2015	2918	38135	1726	2577	615	46051
2030	3571	44207	2301	3474	721	54386
Edible oils						
1995	568	7341	102	1855	54	9934
2000	632	8151	118	2177	58	11153
2015	826	10355	174	3262	69	14712
2030	1009	11870	230	4373	80	17597
Vegetables						
1995	1356	69117	1299	3282	675	75836
2000	1577	83388	1600	4065	789	91557
2015	2239	123824	2612	6735	1113	136763
2030	2821	150823	3601	9391	1377	168358
Fruits						
1995	1602	39867	568	6106	755	48968
2000	1907	47688	710	7720	859	58972
2015	2830	69678	1189	13292	1151	88295
2030	3627	84336	1656	18813	1397	110055
Sweeteners						
1995	1089	22693	61	3524	352	27758
2000	1199	24977	70	4083	375	30749
2015	1537	31220	100	5967	444	39337
2030	1861	35561	131	7925	514	46086
Milk						
1995	2181	65347	1044	18129	526	87350
2000	2564	76932	1292	22487	609	104042
2015	3720	109092	2129	37357	846	153415
2030	4727	130502	2946	52141	1041	191749

Table 8. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Animal fats						
1995	61	1433	28	559	11	2095
2000	72	1687	34	694	12	2503
2015	105	2392	56	1153	17	3729
2030	133	2861	78	1609	21	4712
Meat						
1995	375	4342	189	1697	53	6665
2000	456	5335	241	2133	63	8240
2015	705	8196	422	3634	92	13072
2030	918	10118	598	5123	115	16906
Eggs						
1995	114	1530	23	274	51	1996
2000	139	1880	29	345	61	2457
2015	215	2889	51	587	88	3837
2030	280	3566	72	828	111	4867
Fish						
1995	1066	4482	18	353	323	6242
2000	1297	5507	23	444	383	7653
2015	2005	8460	41	756	558	11820
2030	2612	10444	58	1065	699	14878

Table 9. *Projected demand for food in thousands of tonnes in South Asia with high growth in per capita income.*

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Rice						
1995	20935	78106	2404	2787	2124	106508
2000	22269	84255	2730	3203	2197	114826
2015	26782	101441	3824	4613	2464	139370
2030	31646	113893	4968	6092	2791	159718
Wheat						
1995	2537	59213	873	19002	859	82602
2000	2749	62545	964	21133	897	88421
2015	3422	72411	1280	28624	1025	106951
2030	4097	80087	1629	36920	1169	124157

Table 9. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Maize						
1995	0	9818	1271	1267	67	12440
2000	0	10281	1390	1393	67	13151
2015	0	11714	1814	1847	72	15474
2030	0	12876	2294	2362	81	17649
Other coarse grains						
1995	0	20453	335	714	17	21550
2000	0	21419	366	785	17	22622
2015	0	24403	478	1041	19	25987
2030	0	26825	605	1331	21	28841
Total cereals						
1995	23472	167589	4884	23770	3067	223100
2000	25018	178500	5449	26514	3179	239019
2015	30204	209969	7396	36125	3581	287781
2030	35744	233681	9495	46706	4062	330364
Pulses						
1995	617	14991	191	863	105	16791
2000	702	17028	229	1029	116	19134
2015	960	22578	356	1588	148	25675
2030	1192	26312	482	2153	175	30377
Foodgrains						
1995	24089	182580	5075	24633	3172	239891
2000	25720	195528	5679	27543	3295	258153
2015	31164	232547	7752	37713	3728	313456
2030	36936	259993	9977	48859	4237	360741
Potato						
1995	1491	17747	821	1000	88	21178
2000	1708	20716	994	1217	101	24773
2015	2357	28911	1568	1953	136	34987
2030	2937	34370	2133	2689	166	42382
Other roots and tubers						
1995	508	8403	168	447	378	9919
2000	565	9448	197	527	414	11169
2015	740	12290	292	798	518	14664
2030	904	14217	388	1073	612	17228
Roots and tubers						
1995	1999	26150	990	1447	466	31096
2000	2273	30165	1191	1745	515	35942
2015	3097	41201	1860	2751	654	49650
2030	3841	48587	2521	3763	777	59610

Table 9. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Edible oils						
1995	572	7390	103	1868	54	10002
2000	646	8324	121	2226	59	11394
2015	870	10863	183	3431	72	15446
2030	1074	12581	246	4650	84	18673
Vegetables						
1995	1382	71100	1328	3352	694	77967
2000	1672	91165	1717	4345	861	99910
2015	2562	151861	3068	7840	1359	166985
2030	3325	193562	4383	11304	1759	214773
Fruits						
1995	1643	40921	583	6269	771	50258
2000	2062	51774	770	8389	917	64009
2015	3383	84099	1434	16076	1337	106516
2030	4512	106126	2082	23735	1677	138415
Sweeteners						
1995	1094	22793	61	3537	353	27877
2000	1216	25323	71	4129	379	31164
2015	1586	32213	103	6122	456	40551
2030	1934	36942	136	8175	531	47816
Milk						
1995	2228	66801	1069	18522	539	89287
2000	2746	82451	1392	24062	661	111479
2015	4349	127805	2525	43604	1018	179616
2030	5720	158325	3627	62971	1304	232423
Animal fats						
1995	63	1465	28	572	11	2141
2000	77	1808	37	742	13	2682
2015	122	2802	67	1345	21	4365
2030	161	3471	96	1943	26	5709
Meat						
1995	386	4488	195	1740	55	6873
2000	501	5918	267	2308	70	9077
2015	878	10396	531	4350	116	16299
2030	1201	13534	791	6380	153	22104
Eggs						
1995	118	1582	24	281	53	2060
2000	153	2086	32	373	67	2715
2015	268	3664	64	703	111	4819
2030	366	4770	96	1031	147	6423

Table 9. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Fish						
1995	1099	4632	19	362	333	6445
2000	1427	6108	26	480	424	8465
2015	2497	10731	51	904	703	14887
2030	3417	13971	76	1326	927	19717

Table 10. *Annual growth (per cent) in domestic demand for food in South Asia.*

Food	Low Income Growth			High Income Growth		
	2000-15	2015-30	1995-30	2000-15	2015-30	1995-30
Rice	1.3	0.9	1.2	1.3	0.9	1.2
Wheat	1.4	1.0	1.3	1.3	1.0	1.2
Maize	1.2	0.9	1.1	1.1	0.9	1.0
Other coarse grains	1.1	0.8	0.9	0.9	0.7	0.8
Total cereals	1.3	0.9	1.2	1.3	0.9	1.1
Pulses	1.8	1.0	1.5	2.0	1.1	1.7
Food grains	1.4	1.0	1.2	1.3	0.9	1.2
Roots & Tubers	1.9	1.1	1.6	2.2	1.2	1.9
Edible oil	1.9	1.2	1.6	2.1	1.3	1.8
Vegetables	2.7	1.4	2.3	3.5	1.7	2.9
Fruits	2.7	1.5	2.3	3.4	1.8	2.9
Sweeteners	1.7	1.1	1.5	1.8	1.1	1.6
Milk	2.6	1.5	2.3	3.2	1.7	2.8
Animal fat	2.7	1.6	2.3	3.3	1.8	2.8
Meat	3.1	1.7	2.7	4.0	2.1	3.4
Eggs	3.0	1.6	2.6	3.9	1.9	3.3
Fish	2.9	1.6	2.5	3.8	1.9	3.2

Low income growth: 3.5 per cent annual *per capita* GDP growth.
High income growth: 5.5 per cent annual *per capita* GDP growth.

demand under low and high income scenarios for various time intervals are given in table 10. The results are discussed by country/region in the subsequent sections. This projected demand may be somewhat higher (5 to 10 per cent) if one takes into account export, buffer stock needs, and risk factors.

Bangladesh

Demand for foodgrains of 24 mt in 1995 is projected to grow to about 37 mt in 2030 with a break-down of 32 mt for rice, 4 mt for wheat and 1.1 mt for pulses. These projections are close to the earlier estimates given in the IRRI-IFPRI country study (Shahabuddin and Zohir, 1995). In the year 2000 the demand for roots and tubers works out to about 2.2 mt, edible oil to 0.6 mt, vegetables to 1.6 mt, fruit to 2.0 mt, sugar to 1.2 mt, milk to 2.6-2.7 mt, meat to 0.5 mt, eggs to 0.14-0.15 mt, and fish to 1.3-1.4 mt. In the year 2030, this demand will grow to a level of 3.6-3.8 mt of roots and tubers, 1 mt of edible oils, 2.8-3.3 mt of vegetables, 3.6-4.5 mt of fruit, 1.9 mt of sweeteners, 4.7-5.7 mt of milk, 0.9-1.2 mt of meat, 0.28-0.37 mt of eggs, and 2.6-3.4 mt of fish.

India

The domestic demand for foodgrains is estimated at 197 mt for the year 2000, 232-235 mt for the year 2015 and 260-264 mt for the year 2030. In the year 2030, the domestic demand in India will be about 114 mt for rice, 80-83 mt for wheat, 13 mt for maize, and 24-26 mt for pulses. These projections are lower than the earlier estimates (Kumar, 1998 and Bansil, 1998) become of the lower population projections produced by the recent study by UNFPA and the steady decline in *per capita* consumption of cereals which has not yet stabilised. In the year 2000, the demand for milk is estimated to be 77-82 mt, vegetables 83-91 mt, fruit 48-52 mt, meat 5.3-5.9 mt, eggs 1.9-2.1 mt and fish 5.5-6.1 mt. In the year 2030, total demand is likely to be 130-158 mt for milk, 151-193 mt for vegetables, 84-106 mt for fruit, 10-14 mt for meat, 3.6-4.8 mt for eggs, and 10-14 mt for fish. Income effect on the demand for these non-grain food items is high. The demand for edible oils of 7.3 mt in 1995 will grow to about 12 mt in 2030. Similarly, the demand for sweeteners will increase from a level of 22.7 mt in 1995 to 35.6-36.9 mt in the year 2030.

Nepal

The domestic demand for foodgrains in Nepal is estimated at 5.7 mt for the year 2000, 7.8 mt in 2015, and 10 mt in 2030. Demand for horticultural products, comprising fruit, vegetables and roots and tubers, is estimated at 3.5 mt for the year 2000, and will increase to 7.6 mt in 2030 with low income growth and to 9 mt with high income growth. In the year 2030, livestock product demand is likely to be 2.9-3.6 mt for milk and 0.73-0.96 mt for other livestock and fishery products.

Pakistan

Foodgrain demand in Pakistan, which was 25 mt in 1995, will grow to a level of 38 mt in 2015 and 49-50 mt in 2030 with a break-down of 37-38 mt for wheat, only 6 mt for rice, 3.7-3.9 mt for coarse grains, and 2.0-2.1 mt for pulses. These projections are close to the earlier estimates given in the IRRI-IFPRI country study (Naqvie *et al.*, 1995). In the year 2030 the demand for roots and tubers is estimated at about 3.5-3.8 mt, edible oil 4.4-4.7 mt, vegetables 9-11 mt, fruit 19-24 mt, sweeteners 7.9-8.2 mt, milk 52-63 mt, meat 5.1-6.4 mt, eggs 0.83-1.0 mt, and fish 1.1-1.3 mt.

Sri Lanka

Demand for foodgrains in Sri-Lanka is estimated at 3.3 mt for the year 2000, 3.8 mt in 2015 and 4.3 mt in the year 2030. Demand for other food items in 2030 will be 1.0-1.3 mt for milk, 1.4-1.7 mt for vegetables, 1.4-1.7 mt for fruit, 0.9-1.2 mt for meat, eggs and fish, 80-84 thousand tonnes for edible oils, and 514-531 thousand tonnes for sugar.

South Asia

The domestic demand for food in South Asia is calculated by adding the demand for individual countries, namely, Bangladesh, India, Nepal, Pakistan and Sri Lanka. The demand is adjusted upward in proportion to Bhutan's population share in South Asia. In the year 2000, the demand for rice works out to about 115 mt, wheat 88-89 mt, maize 13 mt, pulses 19 mt, roots and tubers 35-36 mt, edible oils 11 mt, vegetables 92-100 mt, fruits 59-64 mt, sweeteners 31 mt, milk 104-111 mt, animal fats 2.5-2.7 mt, meat 8.2-9.1 mt, eggs 2.5-2.7 mt, and fish 7.7-8.5 mt. In the year 2030, the total foodgrain demand will grow to a level of 361-367 mt, comprising 160-161 mt of rice, 124-129 mt of wheat, 17-19 mt of maize, 29-30 mt of other coarse grains, and 28-30 mt of pulses. IFPRI projections for 2020 (Rosegrant, *et al.*, 1995) for cereals in South Asia appear to be very high (417 mt) as compared to present projections and do not seem to be justified by the cereal consumption pattern prevailing in South Asia. In addition, the projected population is on the higher side in the IFPRI study as compared to recent population projections given by UNFPA. By the year 2030, South Asia will need about 54-60 mt of roots and tubers, 18-19 mt of edible oils, 168-215 mt of vegetables, 110-138 mt of fruit, 46-48 mt of sweeteners, 192-232 mt of milk, 4.7-5.7 mt of animal fat, 17-22 mt of meat, 4.9-6.4 mt of eggs, and 15-20 mt of fish to meet its domestic requirements.

A deceleration in the growth rate of total domestic demand for food was observed (table 10). The demand for cereals during the period 1995-2030 will grow at a slightly lower rate (1.1-1.2 per cent) than the population growth. Demand for roots and tubers, edible oils, and sugar will grow at a moderately higher rate (1.5-1.8 per cent) than population growth. Annual growth in demand for horticultural, livestock and fishery products will grow much faster than the growth in population and foodgrain demand. High growth in livestock demand will put pressure on foodgrains and oil-cakes to meet the feed demand for livestock. Fast growth of income will diversify the dietary pattern in favour of non-foodgrain crops, livestock and fishery products. The *per capita* availability of arable land in South Asia is quite low and declining over time. Diversification towards these high value commodities which are labour intensive can also provide adequate income and employment to the agricultural labourers and farmers who depend on small size farms, and therely help the weaker sections to attain household food security.

Scenario for Food Security

Future increases in the production of food and non-food agricultural commodities have to be essentially achieved through increases in productivity as the possibilities of area and livestock population expansion are minimal. To meet the future demand, the required level of yield and production targets are presented in tables 11 and 12 respectively. To meet the projected demand for food and to attain self-reliance, the South Asia region must attain a per hectare average yield of 2.82 tonnes for rice, 3.72 tonnes for wheat, 2.36 tonnes for maize, and 0.99 tonnes for pulses by the year 2030. This means an improvement in average yield, at the regional level, of 52 per cent in rice, 61 per cent in wheat, 55 per cent in maize, and 77 per cent in pulses. Foodgrains, which contribute more than two-thirds of the calorie intake in the South Asian diet, require substantial increases of 144 per cent in Sri Lanka, 122 per cent in Pakistan, 110 per cent in Nepal, 97 per cent in Bangladesh and 40 per cent in India, by 2030, over the production level in 1995. The required rice yield levels for 2030 in Bangladesh (3.2 t/ha), Nepal (3.48 t/ha), and Sri Lanka (3.2 t/ha) seem to be an unattainable task. Even for India and Pakistan, to attain the rice yield levels of 2.7 t/ha and 2.8 t/ha, respectively, compared to the existing level of 1.7-1.9 t/ha, will not be easy in the existing environment of decelerating growth in factor productivity. For wheat and pulses as well, the required yield target seems to be difficult to attain by most of the South Asian countries. For India, average yields of wheat must reach 3.3 t /ha by 2030, from the exist-

Table 11. *Target yield (tonnes per hectare) levels to meet the domestic demand for food grains.*

Crop	Year	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Rice	1994-96	1.74	1.92	1.46	1.70	1.96	1.87
	1999-00	2.26	2.00	1.91	1.48	2.56	2.03
	2014-15	2.75	2.41	2.66	2.13	2.90	2.48
	2029-30	3.18	2.70	3.48	2.82	3.23	2.82
Wheat	1994-96	1.88	2.45	1.49	2.00	–	2.31
	1999-00	4.19	2.52	1.54	2.62	–	2.59
	2014-15	5.22	2.97	2.08	3.61	–	3.18
	2029-30	6.25	3.30	2.67	4.69	–	3.72
Maize	1994-96	–	1.52	1.67	1.46	1.04	1.53
	1999-00	–	1.71	1.82	1.60	2.29	1.70
	2014-15	–	2.00	2.43	2.18	2.53	2.05
	2029-30	–	2.21	3.10	2.81	2.85	2.36
Cereals	1994-96	1.74	1.74	1.49	1.79	1.91	1.74
	1999-00	2.35	1.80	1.76	2.19	3.54	1.90
	2014-15	2.87	2.15	2.41	3.04	4.03	2.32
	2029-30	3.41	2.40	3.10	3.95	4.59	2.67
Pulses	1994-96	0.75	0.60	0.61	0.50	0.77	0.60
	1999-00	0.96	0.67	0.73	0.66	2.18	0.65
	2014-15	1.26	0.86	1.08	0.99	2.67	0.85
	2029-30	1.55	0.99	1.44	1.32	3.13	0.99

ing level of 2.45 t/ha. Looking at the past performance of wheat productivity, the target may be possible to attain. To meet the non-foodgrain demand for South Asia, production of livestock, fisheries and horticultural products must be improved by 177-246 per cent by 2030 over the base year 1995. The required improvement in productivity level needs serious efforts by the National Agricultural Research System, policy makers, and farmers. Average yields of most of the commodities are low. The vast agricultural potential still remains highly under-realized. The emphasis in favour of yield improvement must be placed on regions where the current yield levels are low. This requires micro-level planning with location specific emphasis.

Average annual increment in the production of major cereals and other food items during 1965-95 and annual incremental demand during 2000-30 given in table 13 reveal that the additional annual requirement during 2000-

Table 12. *Required increase in production by the year 2030 over 1994-96 average production to meet the domestic demand in South Asia.*

Food item	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
			(per cent)			
Low income growth (3.5 per cent *per capita* GDP growth)						
Rice	88	41	136	65	69	52
Wheat	232	35	79	135	–	61
Maize	–	45	85	93	167	55
Other coarse grains	–	32	109	101	341	35
Total cereals	96	38	109	121	140	54
Pulses	107	64	137	165	307	65
Total food grains	97	40	110	122	144	55
Roots & Tubers	92	67	134	132	64	75
Edible oils	545	40	447	534	–68	83
Sweeteners	145	37	–11	68	236	48
Vegetables	94	135	192	148	127	136
Fruits	164	121	198	261	80	142
Milk	150	108	201	189	265	128
Meat	156	142	244	196	37	159
Eggs	261	146	297	214	127	162
Fish	137	121	215	86	206	124
High income growth (5.5 per cent *per capita* GDP growth)						
Rice	83	41	137	67	65	51
Wheat	232	30	73	125	–	55
Maize	–	38	76	82	152	47
Other coarse grains	–	25	99	90	317	29
Total cereals	92	35	105	113	135	50
Pulses	123	76	158	182	338	77
Total food grains	93	38	107	115	140	52
Roots & Tubers	106	84	156	151	77	92
Edible oils	587	48	485	574	–66	94
Sweeteners	154	42	–8	73	247	54
Vegetables	129	202	255	198	190	201
Fruits	228	178	275	355	116	204
Milk	202	152	271	249	358	177
Meat	235	224	355	268	82	238
Eggs	372	229	425	291	201	246
Fish	210	195	317	132	305	197

Table 13. *Average annual increment in production during 1965-95 and domes demand during 2000-30 for food in South Asia.*

Food item	Production		Demand (3.5% PCGDP)		Demand (5.5% PCGD	
	1965-80	1980-95	2000-15	2015-30	2000-15	2015-30
			(Thousand tonnes)			
Rice						
Bangladesh	226.5	171.4	325.3	341.2	300.9	324.3
India	1537.8	1556.7	1164.6	840.9	1145.7	830.1
Nepal	11.4	19.7	72.2	75.7	72.9	76.3
Pakistan	121.0	46.0	92.6	97.3	94.0	98.6
Sri Lanka	61.2	24.6	19.8	23.0	17.8	21.8
South Asia	1957.9	1818.4	1679.4	1383.6	1636.3	1356.5
Wheat						
Bangladesh	52.5	25.1	44.7	44.9	44.9	45.0
India	1727.0	1713.0	748.8	562.5	657.7	511.7
Nepal	20.1	33.5	22.8	24.7	21.1	23.3
Pakistan	417.8	409.7	543.1	589.8	499.4	553.1
Sri Lanka	–	–	8.9	9.8	8.5	9.6
South Asia	2217.4	2181.3	1372.2	1236.5	1235.3	1147.1
Maize						
India	142.3	189.5	115.3	88.4	95.5	77.5
Nepal	–7.5	37.3	31.7	34.8	28.3	32.0
Pakistan	28.7	20.3	34.3	37.7	30.3	34.3
Sri Lanka	0.7	0.7	0.5	0.6	0.3	0.6
South Asia	164.2	247.8	182.0	162.5	154.9	145.0
Pulses						
Bangladesh	23.9	–5.8	14.6	13.4	17.2	15.5
India	46.0	112.0	313.6	214.1	370.0	248.9
Nepal	2.4	3.2	7.3	7.3	8.5	8.4
Pakistan	–8.2	–8.3	33.5	34.3	37.3	37.7
Sri Lanka	2.4	–0.1	1.7	1.6	2.1	1.8
South Asia	66.5	101.0	371.7	271.9	436.1	313.5
Roots & Tubers						
Bangladesh	57.8	11.1	46.9	39.9	54.9	49.6
India	620.3	464.0	598.0	404.8	735.7	492.4
Nepal	7.8	38.5	38.2	38.3	44.6	44.1
Pakistan	26.7	62.3	58.7	59.8	67.1	67.5
Sri Lanka	19.8	–17.0	7.6	7.1	9.3	8.2
South Asia	732.4	558.9	751.3	555.7	913.9	664.0

Table 13. (*cont.*).

Food item	Production		Demand (3.5% PCGDP)		Demand (5.5% PCGDP)	
	1965-80	1980-95	2000-15	2015-30	2000-15	2015-30
			(Thousand tonnes)			
Edible oils						
Bangladesh	5.0	1.2	12.9	12.2	14.9	13.6
India	71.3	212.5	146.9	101.0	169.3	114.5
Nepal	1.0	0.9	3.7	3.7	4.1	4.2
Pakistan	8.7	21.3	72.3	74.1	80.3	81.3
Sri Lanka	–1.8	1.5	0.7	0.7	0.9	0.8
South Asia	84.2	237.4	237.3	192.3	270.1	215.1
Sweetener						
Bangladesh	8.1	–7.0	22.5	21.6	24.7	23.2
India	245.4	449.1	416.2	289.4	459.3	315.3
Nepal	1.4	0.9	2.0	2.1	2.1	2.2
Pakistan	60.6	60.7	125.6	130.5	132.9	136.9
Sri Lanka	1.5	0.8	4.6	4.7	5.1	5.0
South Asia	317.0	504.5	572.5	449.9	625.8	484.3
Vegetables						
Bangladesh	5.1	25.3	44.1	38.8	59.3	50.9
India	1273.5	1364.9	2695.7	1799.9	4046.4	2780.1
Nepal	24.7	50.5	67.5	65.9	90.1	87.7
Pakistan	63.3	140.8	178.0	177.1	233.0	230.9
Sri Lanka	17.1	12.7	21.6	17.6	33.2	26.7
South Asia	1383.7	1453.4	3013.7	2106.3	4471.7	3185.9
Fruits						
Bangladesh	–7.2	5.1	61.9	53.1	88.1	75.3
India	361.0	1237.3	1466.0	977.2	2155.0	1468.5
Nepal	2.3	28.7	31.9	31.1	44.3	43.2
Pakistan	72.9	131.1	371.5	368.1	512.5	510.6
Sri Lanka	59.7	–45.9	19.5	16.4	28.0	22.7
South Asia	488.8	1356.3	1954.9	1450.7	2833.8	2126.6
Milk						
Bangladesh	14.1	52.5	77.1	67.1	106.9	91.4
India	820.9	2196.0	2144.0	1427.3	3023.6	2034.7
Nepal	11.5	17.4	55.8	54.5	75.5	73.5
Pakistan	157.1	661.5	991.3	985.6	1302.8	1291.1
Sri Lanka	6.8	2.9	15.8	13.0	23.8	19.1
South Asia	1010.4	3940.7	3291.5	2555.6	4542.5	3520.5

Table 13. (*cont.*).

Food item	Production		Demand (3.5% PCGDP)		Demand (5.5% PCGD	
	1965-80	1980-95	2000-15	2015-30	2000-15	2015-30
			(Thousand tonnes)			
Meat						
Bangladesh	6.5	10.6	16.6	14.2	25.1	21.5
India	56.7	107.3	190.7	128.1	298.5	209.2
Nepal	3.3	5.2	12.1	11.7	17.6	17.3
Pakistan	20.5	72.6	100.1	99.3	136.1	135.3
Sri Lanka	–0.13	0.50	1.9	1.5	3.1	2.5
South Asia	86.9	196.1	322.1	255.6	481.5	387.0
Eggs						
Bangladesh	1.6	3.4	5.1	4.3	7.7	6.5
India	25.1	68.4	67.3	45.1	105.2	73.7
Nepal	0.3	0.4	1.5	1.4	2.1	2.1
Pakistan	5.9	12.7	16.1	16.1	22.0	21.9
Sri Lanka	1.0	1.3	1.8	1.5	2.9	2.4
South Asia	33.9	86.2	92.0	68.7	140.3	106.9
Fish						
Bangladesh	–11.0	28.6	47.2	40.5	71.3	61.3
India	74.1	134.4	196.9	132.3	308.2	216.0
Nepal	0.2	0.9	1.2	1.1	1.7	1.7
Pakistan	10.6	19.6	20.8	20.6	28.3	28.1
Sri Lanka	5.7	1.9	11.7	9.4	18.6	14.9
South Asia	79.5	185.4	277.8	203.9	428.1	322.0

PCGDP: *Per capita* GDP growth.

2015 and 2015-2030 for food grains, livestock, horticultural and fisheries products will be much higher, especially in the next decade, than that achieved in the past, except with respect to rice, wheat, maize, pulses and milk in India. In the past, major sources of growth in production were area and yield. However, future growth in food production has to come essentially through increases in yield. In the past, rapid growth in public investment in irrigation and other infrastructure, research, and extension, along with crop production strategy and policy support, has helped to expand agricultural production. The slackness in investment on agricultural research and technology development during the early 1990s is a matter of concern in the context of the continued increase in population, diminishing land and fresh water resources, expanding biotic and abiotic stresses, increasing soil salinity and water logging problems, and decelerating productivity growth. As a result, Asian nations are likely to experience a deficit in production in relation to their domestic need for most of the food commodities. India is the major producer and consumer of food in the South Asia region and has huge potential which remains highly under-realized. Therefore, India has to play a major role not only in maintaining its own self-sufficiency in food production but also in meeting the additional requirement of its neighbouring countries. The right research priorities and production strategies will promote future growth in agriculture and ensure sustainable food and nutrition security.

IV. Strategies for Enhancing Food Production

Sustaining Green Areas as Green

Managing the rice-wheat production system: most of the countries have concentrated on enhanced production of a few commodities such as rice and wheat which can quickly contribute to their total food and agricultural production. This has resulted in a considerable depletion of natural resources, and the rainfed dry areas (with their maximum concentration of resource – poor farmers) have been ignored, thereby aggravating problems of inequality and regional imbalances. This has also led to a high concentration of malnourished people in these rainfed low productive areas. This period has also witnessed a rapid loss of soil nutrients and of agro-biodiversity, including indigenous races and breeds.

The rice-wheat based cropping system, which is widespread in the most fertile areas, is the backbone of food security in South Asia. This system is stagnating and is hardpressed to maintain even the modest growth in demand for these two commodities. Smaller growth in yield and decelerating growth in total factor productivity (TFP) in some high input use areas is a matter of concern. An integrated approach of developing crop varieties with greater efficiency in utilizing nutrients and other natural resources, ameliorating soil related problems through the incorporation of legumes in the cropping systems, and enhancing water use efficiency, will be required to develop location specific management practices to improve factor productivity growth in the rice-wheat system. Countries must strengthen multidisciplinary research and refine their technologies towards the goal of sustaining the productivity of rice-wheat systems (Singh and Paroda, 1994).

Legumes play an important role in improving the sustainability of the system. Ironically, rice and wheat have replaced the principal legumes. With the availability of high-yielding and short duration varieties of improved legumes, there is a need to incorporate them into the rice wheat cropping system in order to improve the sustainability of the system so as to meet the future foodgrain demand without a degradation of the natural resource base (Kumar, *et al.*, 1998).

Enhancing the yield of major commodities: the yield of major crops and livestock in the region is much lower than that in the rest of the world. Considering that the frontiers of expansion of cultivated area are almost closed in the region, the future increase in food production to meet the continuing high demand must come from an increase in yields. There is a need to strengthen the adaptive research and technology assessment, refinement and transfer capabilities of the countries so that the existing wide technology transfer gaps are bridged. For this, an appropriate network of extension service needs to be created to stimulate and encourage both top-down and bottom-up flows of information between farmers, extension workers, and research scientists, to promote the generation, adoption, and evaluation of location specific farm technologies. Ample scope exists for increasing the genetic yield potential of a large number of vegetables, fruits, as well as other food crops and livestock and fisheries products. Besides maintenance breeding, greater efforts should be made towards developing hybrid varieties as well as varieties suitable for export purposes. Agronomic and soil research in the region need to be intensified to address location specific problems, as factor productivity growth is decelerating in major production regimes. Research on coarse grains, pulses and oilseeds must achieve a production breakthrough. Hybrid rice, single cross hybrids of maize, and pigeonpea hybrids offer new opportunities. Soybean, sunflower and oil palm will help in meeting future oil demands successfully. Forest cover must be preserved to keep off climatic disturbances and to provide enough fuel and fodder. The milk, meat and draught capacity of our animals needs to be improved quickly through better management practices.

Arresting deceleration in total factor productivity: more and more cases of deceleration in total factor productivity growth are being reported (Kumar and Mruthyunjaya, 1992; Rosegrant and Evension, 1992; Kumar and Rosegrant, 1994; Kumar, *et al.*, 1998). All the efforts in the future have to be concentrated on breaking the yield plateau, whilst conserving natural resources and promoting the ecological integrity of the agricultural system. Producing more with less inputs will be the major challenge of the next two decades. On the whole suggested measures to accelerate and sustain growth in TFP propose investment in research and infrastructural facilities and increasing input use efficiency (Kumar and Rosegrant, 1994). Bio-technology research to address biotic and abiotic stresses should receive more attention. Given the declining trend in public investment in agriculture, which can hardly be reversed, the only option to accelerate growth in TFP is to increase yield potential by developing appropriate technology, both for irrigated and rainfed areas. Research problems in rainfed unfavourable ecosystems and the breaking of current irrigated yield ceilings are more complex and challenging. The achievement of headway will require mobilizing the best of science and the best of scientists in National Agricultural Systems in a partnership mode. This needs higher agricultural research investment which is convincingly justified by several studies (Kumar and Rosegrant, 1994; Jha, *et al.*, 1996; Pal and Singh, 1998).

Integrated nutrient management: attention should be given to the balanced use of nutrients. Phosphorus deficiency is now the most widespread soil fertility problem in both irrigated and unirrigated areas. Correcting the distortion in the relative prices of primary fertilizers could help correct the imbalances in the use of primary plant nutrients – nitrogen, phosphorus, and potash, and the use of biofertilizers. To improve efficiency in fertilizer use, what is really needed is enhanced location-specific research on efficient fertilizer practices (such as the balanced use of nutrients, the correct timing and placement of fertilizers, and, wherever necessary, the use of micronutrient and soil amendments), improvement in soil testing services, the development of improved fertilizer supply and distribution systems, and the development of physical and institutional infrastructures (Kumar and Desai, 1995).

Making Grey Areas Green

Resource-poor farmers in the rainfed ecosystems practice less-intensive agriculture, and since their incomes depend on local agriculture they benefit little from increased food production in irrigated areas. To help them, efforts must be increased to disseminate available dry land technologies and to generate new ones. It will be necessary to enlarge the efforts in favour of promoting available dry land technologies, increasing the stock of this knowledge, and removing pro-irrigation biases in public investment and expenditure, as well as credit flows for technology-based agricultural growth. Watershed development for raising the yields of rainfed crops and a widening of the seed revolution to cover oilseeds, pulses, fruits and vegetables is also needed. Farming system research to develop location specific technologies must be intensified in the rainfed areas. This strategy to make the grey areas green will lead to a second Green Revolution, which will demand a three-pronged strategy: watershed management, hybrid technology, and small farm mechanisation.

Diversification of Agriculture and Value Addition

In the face of shrinking natural resources and an ever increasing demand for larger food and agricultural production caused by high population and income growth, agricultural intensification is the main course for the future growth of agriculture in the region. Research into product diversification should be another important area. Besides developing technologies for promoting intensification, South Asian countries must give greater attention to the development of technologies which will facilitate agricultural diversification, particularly towards the intensive production of fruits, vegetables, flowers and other high value crops which are expected to increase income growth and generate effective demand for food. The *per capita* availability of arable land in South Asia is quite low and declining over time. Diversification towards these high value and labour intensive commodities can provide adequate income and employment for the farmers dependent on small size farms. Due importance should be given to quality and nutritional aspects. High attention should be given to developing post-harvest handling and agro-processing and value addition technologies, not only to reduce the heavy post-harvest losses but also improve quality through proper storage, packaging, handling and transport. The role of biotechnology in post-harvest management and value addition deserves to be enhanced.

V. Summary and Conclusions

South Asia has the highest population pressure on land and other resources to meet its food and development needs. These countries, with a total population of about 1291.2 million people in 1998, account for 21.8 per cent of the world's population and have only 3 per cent of the world's land area. During the last three decades, the South Asia region has made remarkable progress in its food production. Public investment in infrastructure, research and extension, along with production strategy and policy support, have significantly helped to expand food production. It is on account of these that the region witnessed the Green, White and Blue Revolutions.

A structural shift in dietary pattern towards livestock, fisheries, and horticultural products is already underway, and it is predicted that this will intensify further. A decline in *per capita* consumption of cereals and a rapid increase in consumption of fruits, vegetables, milk, meat, eggs and fish is observed. The level of consumption of high value foods is muck lower than the recommended levels. Cereals contribute two-thirds of the total calorie intake and hold the key to nutritional food security in South Asia.

The population of South Asia will be 1930 million in the year 2030. At a 3.5 per cent growth in *per capita* annual real income, the demand for cereals will be 339 million tons (mt), pulses 28 mt, roots and tubers 54 mt, edible oils 18 mt, vegetables 168 mt, fruits 110 mt, sugars 46 mt, milk 191 mt, animal fats 4.7 mt, meat 17 mt, eggs 4.9 mt and fish 15 mt. To meet the projected demand for food and to attain self-reliance, the South Asia region must attain a per hectare yield of 2.82 tons for rice, 3.72 tons for wheat, 2.36 for maize, and 0.99 tons for pulses by the year 2030. This means an improvement in average yields, at the regional level, of 55 per cent in rice, 61 per cent in wheat, 55 per cent in maize, and 77 per cent in pulses. The production of livestock, fisheries and horticultural products must be improved by 177-246 per cent by 2030 starting from the year 1995. The additional annual requirement of food in the next century is predicted to be much more than that achieved in the past by the South Asian countries. Future increases in the production of cereals and non-cereal agricultural commodities will have to be essentially achieved through increases in productivity, as the possibilities of expansion in the area and in livestock population are minimal. Vast opportunities to harness agricultural potential still remain to be tapped to achieve future targets. There are serious gaps both in yield potential and technology transfer, as the national average yields of most of the commodities are low, which, if addressed properly, could be harnessed.

Future food demand challenges are formidable considering the non-availability of a favourable environment of past growth, declining factor productivity in major cropping systems, and the shrinking resource base. Furthermore, capital investment in agriculture is declining in most of the South Asian countries. Managing the rice-wheat production system, enhancing the yields of major commodities, arresting deceleration in factor productivity, improving productivity in rainfed agriculture, integrated nutrient management and post-harvest management, and value addition will be the major strategies for these nations. These strategies need to be blended with farmers' wisdom to ensure the adoption of improved technologies. Thus, to ensure food security, more capital investment in agriculture, including greater support to research and development, will be critical in the future. However, serious efforts by the National Agricultural Research System, policy makers and the hard working innovative farmers of South Asia would, no doubt, be able to convert these formidable challenges into great successes in the future as well.

APPENDICES

Appendix 1. *Average annual growth rates (per cent) in area, production, yield major cereals in South Asia.*

	Rice			Wheat			Coarse Grains		
	1969-78	1978-87	1987-96	1969-78	1978-87	1987-96	1969-78	1978-87	1987-96
Bangladesh									
Area	0.18	0.31	–0.63	5.13	13.83	1.11	–2.46	8.33	–4.14
Production	1.37	2.17	1.49	12.10	16.28	0.94	–4.27	9.87	–3.96
Yield	1.19	1.86	2.13	6.96	2.45	–0.17	–1.81	1.55	0.18
Bhutan									
Area	2.02	2.67	–2.66	3.14	4.30	–5.08	2.12	1.52	–1.01
Production	2.07	2.22	–3.50	3.14	4.10	–4.86	2.32	0.55	–2.84
Yield	0.05	–0.45	–0.83	0.00	–0.20	0.22	0.20	–0.97	–1.83
India									
Area	0.74	0.29	0.44	3.33	1.30	0.90	–1.07	–0.97	–2.22
Production	2.16	2.78	3.16	5.77	5.03	3.56	1.17	–0.57	1.28
Yield	1.41	2.48	2.72	2.44	3.73	2.66	2.24	0.40	3.50
Nepal									
Area	1.03	1.63	–0.21	6.85	5.59	1.03	0.77	6.20	1.03
Production	1.16	2.61	0.51	7.34	7.07	2.61	–0.04	4.44	2.94
Yield	0.13	0.98	0.72	0.49	1.48	1.59	–0.81	–1.76	1.91
Pakistan									
Area	2.20	0.13	0.78	0.34	1.88	1.18	–0.79	0.04	0.11
Production	3.70	0.59	1.61	3.91	3.89	3.19	0.77	1.27	1.36
Yield	1.50	0.46	0.83	3.57	2.01	2.01	1.56	1.23	1.25
Sri Lanka									
Area	2.30	0.63	1.40	–	–	–	9.03	–3.11	–2.06
Production	0.54	4.72	1.06	–	–	–	7.18	1.36	–3.25
Yield	–1.76	4.09	–0.34	–	–	–	–1.85	4.47	–1.19

Appendix 1. (*cont.*).

	Rice			Wheat			Coarse Grains		
	1969-78	1978-87	1987-96	1969-78	1978-87	1987-96	1969-78	1978-87	1987-96
South Asia									
Area	0.71	0.33	0.26	2.62	1.64	0.97	–1.03	–0.76	–2.03
Production	2.01	2.60	2.72	5.35	4.96	3.42	1.11	–0.28	1.32
Yield	1.30	2.27	2.46	2.73	3.32	2.45	2.14	0.49	3.35
World									
Area	1.13	0.08	0.28	0.81	–0.12	–0.18	0.48	–0.06	–0.37
Production	2.58	3.04	1.73	3.08	2.69	0.95	2.73	1.58	0.79
Yield	1.45	2.96	1.45	2.27	2.81	1.14	2.25	1.64	1.16

Source: Computed from the FAOSTAT data based on three years moving averages.

Appendix 2. *Annual per capita consumption in kg.*

Food item	Bangladesh		India		Pakistan		Nepal	Sri Lanka
	1981	1988	1977	1993	1979	1993	1993	1993
Rice	98.0	163.5	82.7	79.9	14.9	16.1	62.9	72.5
Wheat	23.9	21.5	52.4	54.5	134.4	124.6	33.3	46.6
Coarse grains & cereal substitutes	3.8	3.4	48.4	19.8	10.5	8.2	61.6	18.2
Pulses	5.3	8.2	9.3	9.5	8.0	8.1	8.3	5.5
Vegetables	38.9	78.6	27.7	55.8	31.8	65.4	79.3	34.7
Fruits	2.9	5.0	3.3	12.5	7.8	15.7	22.6	36.1
Milk	7.1	8.2	26.6	55.8	59.0	87.3	35.9	27.1
Meat, eggs & fish	11.4	12.9	3.1	4.6	8.1	8.1	9.9	18.7
Edible oils	2.3	3.7	3.1	5.0	4.3	10.8	3.9	2.7
Sugar	3.5	3.4	14.2	9.9	14.5	17.8	6.0	19.3

Sources of data: Bangladesh Bureau of Statistics, Report on the household expenditure survey 1988-89.
Household income and expenditure survey, Federal Bureau of Statistics, Islamabad.
Household Expenditure consumer survey data, 50th National Sample Survey round, CSO, India.
For Nepal and Sri Lanka, availability of food is taken from FAOSTATE.

Appendix 3. *Average Annual per capita availability* (kg) *of food items in South Asia, 1992-94.*

Food items	Bangladesh	India	Pakistan	Nepal	Sri Lanka
Cereals	184.9	157.7	155.6	190.0	159.1
Rice	165.0	76.1	18.1	94.4	108.7
Wheat	19.9	55.7	128.9	33.3	46.6
Maize	0.0	8.4	5.5	49.3	3.1
Other coarse grains	0.0	17.5	3.1	13.0	0.8
Pulses	4.7	13.1	4.6	7.7	5.5
Roots & Tubers	13.4	20.7	8.6	33.0	17.7
Potato	9.9	13.6	5.8	27.2	3.3
Other roots & tubers	3.5	7.1	2.8	5.8	14.4
Horticultural products	21.8	99.8	58.1	74.9	67.7
Vegetables	10.1	64.2	20.9	52.2	31.6
Fruits	11.7	35.6	37.2	22.7	36.1
Edible oils	4.2	7.1	12.6	3.9	2.1
Sweeteners	7.3	23.7	25.0	2.8	19.3
Livestock products	18.0	64.9	118.9	46.4	32.8
Milk	14.1	57.7	102.1	36.1	27.1
Meat	3.0	4.4	11.9	8.2	2.8
Eggs	0.7	1.4	1.6	0.9	2.5
Animal fats	0.2	1.4	3.3	1.2	0.4
Fisheries products	8.5	4.1	2.3	0.8	15.8

Appendix 4. *Projected annual per capita food consumption* (Kg) *in South Asia with low income growth.*

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Rice						
1995	164.1	76.0	94.5	18.1	108.2	78.9
2000	162.3	75.8	94.7	18.2	107.1	78.2
2015	159.0	75.5	95.1	18.3	105.1	76.6
2030	157.7	75.4	95.3	18.4	104.3	75.7
Wheat						
1995	19.9	55.3	33.1	127.9	46.5	59.4
2000	19.9	54.4	32.5	125.7	46.3	58.9
2015	19.9	52.9	31.6	121.6	46.0	58.4
2030	19.9	52.3	31.2	120.1	45.9	58.8
Maize						
1995	.0	8.3	48.8	5.4	3.1	7.8
2000	.0	8.1	47.7	5.3	3.0	7.7
2015	.0	7.8	45.8	5.1	2.9	7.4
2030	.0	7.7	45.1	5.0	2.8	7.3
Other coarse grains						
1995	.0	17.3	12.9	3.1	.8	13.7
2000	.0	17.0	12.6	3.0	.8	13.4
2015	.0	16.3	12.1	2.9	.7	12.7
2030	.0	16.1	11.9	2.8	.7	12.2
Total cereals						
1995	184.0	157.0	189.2	154.5	158.6	159.9
2000	182.2	155.4	187.6	152.1	157.2	158.2
2015	178.9	152.5	184.6	147.9	154.7	155.1
2030	177.6	151.5	183.5	146.3	153.7	154.0
Total Pulses						
1995	4.8	13.3	7.8	4.7	5.6	10.8
2000	4.9	13.7	8.1	4.8	5.8	11.1
2015	5.2	14.5	8.7	5.0	6.1	11.6
2030	5.4	14.8	9.0	5.1	6.3	11.7
Foodgrains						
1995	188.8	170.2	197.1	159.1	164.1	171.2
2000	187.2	169.1	195.7	156.9	162.9	169.8
2015	184.1	167.0	193.4	152.9	160.8	167.2
2030	183.0	166.3	192.5	151.4	160.0	166.2

Appendix 4. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Potato						
1995	10.1	13.9	27.7	5.9	3.4	12.7
2000	10.4	14.6	29.0	6.2	3.6	13.3
2015	11.2	16.0	31.4	6.6	3.9	14.4
2030	11.4	16.5	32.4	6.8	4.1	14.8
Other roots and tubers						
1995	3.5	7.2	5.9	2.8	14.6	6.4
2000	3.6	7.4	6.0	2.9	15.0	6.6
2015	3.7	7.7	6.2	3.0	15.7	6.8
2030	3.8	7.8	6.3	3.0	16.1	6.8
Total roots and tubers						
1995	13.6	21.1	33.6	8.7	18.0	19.2
2000	14.0	21.9	34.9	9.0	18.5	19.9
2015	14.9	23.7	37.6	9.6	19.7	21.2
2030	15.2	24.4	38.7	9.9	20.1	21.5
Edible oils						
1995	4.3	7.2	4.0	12.8	2.1	7.4
2000	4.4	7.4	4.1	13.1	2.2	7.6
2015	4.6	7.7	4.3	13.8	2.2	8.1
2030	4.7	7.9	4.4	14.0	2.3	8.3
Vegetables						
1995	10.4	67.5	54.3	21.7	33.2	56.2
2000	11.2	75.3	59.1	23.5	36.9	62.2
2015	12.8	92.2	69.4	27.3	45.1	74.8
2030	13.5	99.8	73.8	29.0	48.7	79.2
Fruits						
1995	12.2	37.3	23.8	39.0	37.5	34.8
2000	13.4	41.2	26.3	43.1	40.5	38.5
2015	16.1	49.7	31.6	52.1	47.0	46.4
2030	17.2	53.4	34.0	56.1	49.8	49.7
Sweeteners						
1995	7.4	23.9	2.8	25.2	19.4	22.0
2000	7.5	24.3	2.9	25.5	19.7	22.4
2015	7.7	25.0	2.9	26.1	20.2	23.0
2030	7.8	25.3	3.0	26.4	20.4	23.2
Milk						
1995	14.7	60.0	37.7	106.1	28.4	59.9
2000	15.9	65.2	41.2	115.1	31.3	65.4
2015	18.6	76.3	48.8	134.2	37.6	77.5
2030	19.7	81.1	52.1	142.4	40.4	83.2

Appendix 4. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Animal fats						
1995	.2	1.5	1.3	3.4	.4	1.5
2000	.2	1.6	1.4	3.7	.4	1.7
2015	.3	1.9	1.6	4.3	.5	2.0
2030	.3	2.0	1.7	4.6	.6	2.2
Meat						
1995	3.2	4.7	8.7	12.4	3.0	5.4
2000	3.6	5.3	9.8	13.7	3.4	6.2
2015	4.4	6.7	12.3	16.4	4.2	7.9
2030	4.8	7.4	13.5	17.5	4.6	8.8
Eggs						
1995	.8	1.4	1.0	1.7	2.6	1.4
2000	.9	1.6	1.1	1.9	3.0	1.6
2015	1.1	2.1	1.4	2.2	3.8	2.0
2030	1.2	2.3	1.5	2.4	4.1	2.2
Fish						
1995	9.0	4.3	.8	2.4	16.7	4.7
2000	10.1	4.9	1.0	2.6	18.9	5.3
2015	12.5	6.3	1.2	3.1	23.8	6.6
2030	13.7	6.9	1.3	3.3	26.0	7.1

Appendix 5. *Projected annual per capita food consumption* (Kg) *in South Asia with high income growth.*

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Rice						
1995	163.6	76.0	94.6	18.1	107.9	78.8
2000	160.8	75.7	94.9	18.3	106.2	77.9
2015	155.6	75.2	95.5	18.4	103.0	76.1
2030	153.6	75.0	95.8	18.5	101.9	75.0
Wheat						
1995	19.9	55.1	32.9	127.3	46.5	59.2
2000	19.9	53.7	32.1	123.8	46.2	58.2
2015	20.0	51.3	30.6	117.7	45.7	56.7
2030	20.0	50.4	30.1	115.4	45.5	56.7
Maize						
1995	.0	8.3	48.5	5.4	3.0	7.8
2000	.0	8.0	46.9	5.2	2.9	7.5
2015	.0	7.5	44.0	4.8	2.7	7.1
2030	.0	7.3	42.9	4.7	2.7	7.0
Other coarse grains						
1995	.0	17.2	12.8	3.0	.8	13.7
2000	.0	16.7	12.4	2.9	.8	13.2
2015	.0	15.7	11.6	2.7	.7	12.1
2030	.0	15.3	11.3	2.6	.7	11.6
Total cereals						
1995	183.6	156.5	188.8	153.9	158.2	159.4
2000	180.7	154.1	186.2	150.2	156.0	156.8
2015	175.6	149.7	181.7	143.7	152.1	152.1
2030	173.6	148.1	180.1	141.3	150.7	150.3
Pulses						
1995	4.8	13.4	7.9	4.7	5.6	10.9
2000	5.1	14.1	8.4	4.9	5.9	11.4
2015	5.6	15.4	9.4	5.3	6.5	12.3
2030	5.8	15.9	9.8	5.5	6.7	12.5
Foodgrains						
1995	188.4	169.9	196.7	158.5	163.8	170.8
2000	185.8	168.1	194.6	155.1	162.0	168.7
2015	181.1	165.1	191.1	149.0	158.6	164.9
2030	179.4	164.0	189.9	146.7	157.4	163.4

Appendix 5. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Potato						
1995	10.2	14.1	28.1	6.0	3.4	12.9
2000	10.7	15.2	30.0	6.4	3.7	13.8
2015	11.9	17.5	34.0	7.2	4.4	15.7
2030	12.4	18.5	35.7	7.5	4.6	16.4
Other roots and tubers						
1995	3.5	7.2	5.9	2.8	14.7	6.5
2000	3.6	7.5	6.1	2.9	15.3	6.7
2015	3.8	8.1	6.5	3.1	16.6	7.1
2030	3.9	8.3	6.6	3.2	17.1	7.2
Roots and tubers						
1995	13.7	21.3	34.0	8.8	18.1	19.4
2000	14.4	22.7	36.1	9.3	19.0	20.5
2015	15.8	25.5	40.5	10.3	20.9	22.8
2030	16.4	26.7	42.4	10.7	21.7	23.6
Edible oils						
1995	4.3	7.2	4.0	12.8	2.1	7.4
2000	4.5	7.5	4.2	13.4	2.2	7.8
2015	4.8	8.1	4.5	14.5	2.3	8.5
2030	5.0	8.3	4.7	14.9	2.4	8.8
Vegetables						
1995	10.6	69.5	55.5	22.2	34.1	57.8
2000	11.9	82.3	63.5	25.1	40.3	67.9
2015	14.7	113.1	81.5	31.8	55.0	91.3
2030	15.9	128.0	89.8	34.9	62.2	101.1
Fruits						
1995	12.5	38.3	24.4	40.0	38.2	35.7
2000	14.5	44.7	28.5	46.9	43.3	41.8
2015	19.2	60.0	38.1	63.0	54.6	55.9
2030	21.4	67.2	42.7	70.7	59.8	62.6
Sweeteners						
1995	7.4	24.0	2.8	25.2	19.5	22.1
2000	7.6	24.6	2.9	25.8	19.9	22.7
2015	8.0	25.8	3.0	26.8	20.8	23.7
2030	8.1	26.3	3.1	27.2	21.1	24.1
Milk						
1995	15.0	61.3	38.6	108.4	29.1	61.2
2000	17.0	69.9	44.4	123.2	33.9	70.1
2015	21.7	89.4	57.8	156.6	45.2	90.7
2030	23.9	98.4	64.1	172.0	50.6	100.8

Appendix 5. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Animal fats						
1995	.2	1.5	1.3	3.5	.4	1.6
2000	.2	1.7	1.5	4.0	.5	1.8
2015	.3	2.2	1.9	5.1	.6	2.4
2030	.3	2.4	2.1	5.6	.7	2.6
Meat						
1995	3.3	4.8	9.0	12.8	3.1	5.6
2000	3.9	5.9	10.8	14.8	3.7	6.8
2015	5.5	8.5	15.5	19.6	5.3	9.8
2030	6.3	9.8	17.8	21.8	6.1	11.4
Eggs						
1995	.8	1.5	1.0	1.7	2.7	1.5
2000	1.0	1.8	1.2	2.0	3.3	1.8
2015	1.3	2.6	1.7	2.7	4.7	2.5
2030	1.5	3.0	2.0	3.0	5.5	2.9
Fish						
1995	9.3	4.5	.9	2.4	17.3	4.8
2000	11.1	5.5	1.1	2.8	20.9	5.8
2015	15.6	7.9	1.5	3.7	30.0	8.3
2030	17.9	9.2	1.7	4.2	34.5	9.4

Appendix 6. *Projected population in South Asia.*

YEAR	Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka	South Asia
Projected population (millions)							
1995	118.2	1.7	930.4	21.5	136.4	18.0	1226.3
1998*	124.0	1.9	975.8	23.2	147.8	18.5	1291.2
2000	128.0	2.0	1007.3	24.4	155.9	18.9	1336.4
2005	138.2	2.3	1084.6	27.4	177.2	19.8	1449.6
2010	148.6	2.6	1156.0	30.6	199.4	20.8	1558.0
2015	159.1	2.9	1221.0	33.9	222.2	21.8	1660.9
2020	169.6	3.3	1279.1	37.2	245.5	22.8	1757.4
2025*	180.0	3.6	1330.2	40.6	268.9	23.9	1847.2
2030	190.4	4.0	1374.4	43.9	292.3	25.0	1929.9
Share of population as percentage of total South Asian population							
1995	9.5	0.1	75.9	1.8	11.1	1.5	100
2000	9.5	0.2	75.4	1.8	11.7	1.4	100
2015	9.6	0.2	73.5	2.0	13.4	1.3	100
2030	9.9	0.2	71.2	2.3	15.1	1.3	100
Population growth (per cent per annum)							
1995-2000	1.60	2.80	1.60	2.50	2.70	1.00	1.73
2000-2010	1.50	2.66	1.39	2.29	2.49	0.96	1.55
2010-2020	1.33	2.41	1.02	1.97	2.10	0.92	1.21
2020-2030	1.16	1.94	0.72	1.67	1.76	0.92	0.94
1995-2030	1.37	2.47	1.12	2.06	2.20	0.94	1.30

* *Source:* The State of World Population 1998, UNFPA. Other figures are computed from the predicted population.

Appendix 7. *Projected human demand for food in thousand tonnes with low income growth scenario.*

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Rice						
1995	19407	70729	2036	2473	1943	96724
2000	20776	76398	2308	2837	2021	104496
2015	25286	92207	3226	4070	2291	127305
2030	30016	103622	4187	5367	2606	146098
Wheat						
1995	2353	51446	712	17440	835	72890
2000	2549	54832	793	19589	874	78756
2015	3172	64550	1071	27030	1003	96997
2030	3797	71851	1372	35112	1146	113510
Maize						
1995	0	7739	1051	742	55	9600
2000	0	8203	1164	827	56	10265
2015	0	9559	1555	1125	62	12323
2030	0	10599	1983	1454	70	14135
Other coarse grains						
1995	0	16122	277	418	14	16856
2000	0	17089	307	466	15	17904
2015	0	19914	410	634	16	21012
2030	0	22080	523	820	18	23489
Total cereals						
1995	21760	146036	4076	21072	2847	196071
2000	23325	156522	4571	23719	2966	211421
2015	28458	186230	6261	32860	3373	257636
2030	33813	208152	8065	42753	3840	297233
Total Pulses						
1995	564	12364	169	635	100	13852
2000	631	13802	198	746	109	15509
2015	833	17713	296	1119	133	20130
2030	1020	20384	394	1500	156	23503
Total foodgrains						
1995	22324	158400	4245	21708	2947	209923
2000	23956	170323	4770	24465	3075	226930
2015	29291	203943	6557	33979	3507	277766
2030	34834	228536	8459	44254	3997	320736

Appendix 7. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Potato						
1995	1190	12941	598	806	61	15618
2000	1335	14700	706	959	67	17794
2015	1774	19492	1064	1475	86	23933
2030	2179	22716	1422	1997	102	28474
Other roots and tubers						
1995	417	6681	126	386	262	7883
2000	460	7409	146	450	283	8760
2015	591	9394	211	666	343	11225
2030	716	10759	278	888	401	13069
Total roots and tubers						
1995	1607	19621	724	1192	323	23501
2000	1795	22109	852	1409	350	26555
2015	2365	28886	1275	2140	429	35157
2030	2895	33475	1700	2885	503	41543
Edible oils						
1995	503	6684	85	1740	38	9063
2000	560	7421	99	2043	41	10178
2015	732	9428	145	3060	49	13438
2030	893	10807	192	4102	57	16084
Vegetables						
1995	1235	62827	1170	2960	596	68886
2000	1435	75800	1441	3666	697	83165
2015	2038	112556	2353	6074	983	124222
2030	2568	137098	3244	8469	1216	152909
Fruits						
1995	1446	34700	512	5318	673	42710
2000	1721	41507	640	6724	765	51434
2015	2553	60648	1072	11577	1025	77011
2030	3273	73406	1493	16386	1244	95999
Sweeteners						
1995	870	22221	61	3432	349	26971
2000	957	24457	70	3975	372	29876
2015	1227	30570	100	5810	441	38216
2030	1486	34821	131	7716	510	44757

Appendix 7. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Milk						
1995	1733	55826	811	14468	509	73452
2000	2037	65723	1004	17947	590	87434
2015	2956	93197	1654	29815	820	128668
2030	3756	111488	2289	41614	1008	160483
Animal fats						
1995	25	1355	27	468	7	1883
2000	29	1595	33	580	8	2248
2015	42	2261	55	964	11	3339
2030	53	2705	76	1345	14	4202
Meat						
1995	375	4342	187	1697	53	6663
2000	456	5335	239	2133	63	8238
2015	705	8196	418	3634	92	13068
2030	918	10118	592	5123	115	16900
Eggs						
1995	91	1332	21	232	48	1726
2000	111	1637	26	292	56	2126
2015	171	2515	46	498	82	3318
2030	223	3104	65	702	103	4206
Fish						
1995	1061	4046	18	324	300	5758
2000	1291	4971	23	407	357	7059
2015	1996	7637	41	693	519	10906
2030	2601	9428	58	977	651	13742

Appendix 8. *Projected human demand for food in thousands of tonnes with high income growth scenario.*

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Rice						
1995	19348	70686	2037	2475	1937	96621
2000	20581	76251	2313	2845	2003	104150
2015	24752	91804	3240	4098	2247	126364
2030	29248	103073	4210	5412	2545	144784
Wheat						
1995	2354	51231	709	17359	834	72590
2000	2551	54114	782	19305	872	77740
2015	3175	62650	1039	26148	996	94174
2030	3802	69291	1322	33726	1136	109502
Maize						
1995	0	7695	1045	737	55	9545
2000	0	8058	1142	810	55	10081
2015	0	9181	1491	1074	59	11826
2030	0	10092	1885	1373	66	13445
Other coarse grains						
1995	0	16031	276	415	14	16760
2000	0	16788	301	456	14	17587
2015	0	19127	393	605	15	20176
2030	0	21026	497	774	17	22360
Total cereals						
1995	21702	145643	4066	20986	2840	195516
2000	23132	155211	4538	23416	2945	209557
2015	27927	182763	6163	31925	3318	252541
2030	33050	203482	7914	41286	3764	290090
Pulses						
1995	569	12465	170	640	101	13965
2000	648	14159	205	763	112	15911
2015	886	18773	318	1178	142	21334
2030	1100	21878	430	1597	168	25225
Foodgrains						
1995	22271	158108	4237	21626	2941	209481
2000	23780	169370	4743	24179	3056	225468
2015	28813	201536	6481	33103	3460	273875
2030	34150	225360	8344	42882	3933	315315

Appendix 8. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Potato						
1995	1202	13106	605	815	62	15811
2000	1376	15299	731	992	70	18497
2015	1899	21351	1154	1592	95	26136
2030	2366	25382	1570	2192	116	31691
Other roots and tubers						
1995	419	6724	127	388	264	7932
2000	467	7560	148	457	289	8935
2015	611	9833	220	692	361	11738
2030	747	11375	292	931	427	13799
Roots and tubers						
1995	1621	19830	731	1202	325	23744
2000	1843	22859	880	1450	359	27431
2015	2510	31184	1374	2284	456	37875
2030	3113	36757	1862	3123	542	45490
Edible oils						
1995	507	6729	86	1752	38	9125
2000	573	7579	101	2088	41	10398
2015	771	9890	154	3218	50	14108
2030	951	11455	205	4362	59	17068
Vegetables						
1995	1258	64630	1196	3023	613	70821
2000	1522	82869	1547	3918	760	90753
2015	2332	138042	2764	7071	1200	151676
2030	3027	175948	3948	10195	1553	195071
Fruits						
1995	1482	35618	526	5461	687	43835
2000	1860	45065	694	7307	817	55827
2015	3053	73199	1293	14002	1191	92901
2030	4071	92372	1877	20673	1493	120733
Sweeteners						
1995	874	22319	61	3444	350	27086
2000	971	24796	71	4020	376	30280
2015	1267	31543	103	5961	453	39395
2030	1545	36174	136	7960	527	46436

Appendix 8. (*cont.*).

YEAR	Bangladesh	India	Nepal	Pakistan	Sri Lanka	South Asia
Milk						
1995	1771	57068	830	14783	523	75081
2000	2182	70438	1082	19204	640	93686
2015	3456	109183	1961	34800	986	150652
2030	4545	135257	2818	50257	1263	194539
Animal fats						
1995	25	1385	28	478	7	1925
2000	31	1709	36	621	9	2409
2015	49	2649	65	1125	13	3909
2030	64	3282	94	1624	17	5092
Meat						
1995	386	4488	193	1740	55	6871
2000	501	5918	264	2308	70	9074
2015	878	10396	526	4350	116	16293
2030	1201	13534	784	6380	153	22097
Eggs						
1995	94	1377	21	238	49	1782
2000	122	1816	29	316	62	2349
2015	214	3190	58	596	104	4168
2030	292	4153	86	874	137	5553
Fish						
1995	1094	4182	19	332	310	5945
2000	1421	5514	26	440	395	7807
2015	2486	9687	51	830	654	13733
2030	3402	12611	76	1217	863	18207

Appendix 9. *Share of seed, feed, wastage and other than food uses as percentage of total supply 1992-94 averages.*

Food items	Bangladesh	India	Nepal	Pakistan	Sri Lanka
Rice	7.58	9.50	15.27	11.17	8.81
Wheat	7.21	13.48	18.82	8.65	2.87
Coarse grains	57.14	21.62	17.80	41.86	17.91
Roots & Tubers	17.41	19.99	24.62	13.28	30.24
Pulses	7.71	16.85	10.80	25.84	3.90
Vegetable oils	11.44	8.95	16.32	6.19	29.7
Sweeteners	20.13	2.08	0.00	2.63	0.77
Vegetables	8.97	9.10	9.92	9.81	11.69
Fruits	9.77	12.96	9.85	12.96	10.94
Milk	20.54	14.57	22.31	20.19	3.13
Animal fats	59.90	5.46	2.60	16.40	34.48
Meat	0.00	0.00	0.97	0.00	0.00
Eggs	20.20	12.95	10.00	15.24	7.04
Food	0.44	9.73	0.00	9.73	6.91

REFERENCES

Bansil, P.C. (1998): *Demand for Foodgrains by 2020* (New Delhi, Observer Research Foundation).

Behrman, J., and Deolalikar, A. (1989): 'Is Variety the Spice of Life? Implications for Calorie Intake', *Review of Economics and Statistics*, pp. 331-98.

Boius, H. (1992): *A Food Demand System Based on Demand for Characteristics: If there is Curvature in the Slutsky Matrix, What do the Curves Look Like and Why?* (Washington, D.C., International Food Policy Research Institute).

Bouis, H., and Haddad, L. (1992): 'Are Estimates of Calorie-Income Elasticities too High: A Recalibration of the Plausible Range', *Journal of Development Economics.*

Jha D., Kumar, P., Pal, S., Selvarajan, S., and Singh, A. (1995): 'Research Priorities in Indian Agriculture' (Policy Paper 2. New Delhi, National Centre of Agricultural Economics and Policy Research).

Kumar, P., and Mruthyunjaya (1992): 'Measurement and Analysis of Total Factor Productivity Growth in Wheat', *Indian Journal of Agricultural Economics*, 17(3), pp. 451-58.

Kumar, P., and Rosegrant, M.W. (1994): 'Productivity and Sources of Growth for Rice in India', *Economic and Political Weekly*, 29(53), pp. A183-88.

Kumar, P., and Desai, G.M. (1995): 'Fertiliser Use Pattern in India During the Mid-1980s: Micro-Level Evidence on Marginal and Small Farms', in Desai, Gunvant M. and A. Vaidyanathan (eds.), *Strategic Issues in Future Growth of Fertiliser Use in India* (Delhi, Macmillan India Ltd.).

Kumar, P., Joshi, P.K., Johansen, C., and Asokan, M. (1998): 'Sustainability of Rice-Wheat Based Cropping Systems in India: Socio-Economic and Policy Issues', *Economic and Political Weekly*, 33(39), pp. A152-157.

Kumar, P. (1998): 'Food Demand and Supply Projections for India', *Agricultural Economics Policy Paper 98-01* (New Delhi, Indian Agricultural Research Institute).

Naqvi, S.N.H., Ahmed, A.M., and Siddiqui, R. (1995): *Projections and Policy Implications of Medium and Long-Term Supply and Demand of Major Food Crops in Pakistan. Collaborative Research on Projections and Policy Implications of Medium and Long Term Rice Supply and Demand* (Los Banos, International Rice Research Institute, and Washington D.C., International Food Policy Research Institute).

Pal, S., and Singh, A. (1998): 'Strengthening the Indian Agricultural Research and Extension Systems: Funding and Institutional Imperatives', *Indian Journal of Agricultural Economics*, 53(3), pp. 488-503.

RAPA (1994): *Selected Indicators of Food and Agriculture Development in Asia-Pacific Region, 1983-93* (Bangkok, Food and Agriculture Organization of the United Nations).

Rosegrant, M.W., and Evenson, R.E. (1992): 'Agricultural Productivity and Sources of Growth in South Asia', *American Journal of Agricultural Economics*, 74, pp. 757-61.

Rosegrant, M.W., Agcaoili-Sombilla, M., and Perez, N.D. (1995): *Global Food Projections to 2020: Implications for Investment. Food, Agriculture, and the Environment Discussion Paper 5* (Washington, D.C., International Food Policy Research Institute).

Shahabuddin, Q., and Zohir, S. (1995): *Projections and Policy Implications of Rice Supply and Demand in Bangladesh. Collaborative Research on Projections and Policy Implications of*

Medium and Long Term Rice Supply and Demand (Los Banos, International Rice Research Institute, and Washington D.C., International Food Policy Research Institute).

Singh, R.B., and Paroda, R.S. (1994): 'Sustainability and Productivity of Rice-Wheat Systems in the Asia-Pacific Region: Research & Technology Development Needs', in Paroda, R.S. and R.B. Singh (eds.), *Sustainability of Rice-Wheat Production Systems in Asia* (FAO, RAPA Publication 1994/11, New Delhi, Oxford & IBH Publishing Co. Pvt. Ltd.).

Singh, R.B. (1996): *Agricultural Research Priorities in South Asia* (The Asia-Pacific Association of Agricultural Research Institutions).

UNFPA (1998): *The State of World Population* (United Nations Population Fund).

FOOD PRODUCTION AND THE DEMAND SITUATION IN LATIN AMERICA

FERNANDO MÖNCKEBERG BARROS

The current situation concerning food security in Latin America remains precarious even though it may be considered that, in general, there has been improvement during the last decades. The nutritional situation in the area may be defined as one of chronic underfeeding with shortages in energy and micronutrient intake that affect an important segment of the population, especially children during the first years of life, and pregnant and nursing mothers. As a result, early mortality among the lower income groups remains high in most countries, and the same happens with maternal mortality and the proportion of underweight newborns.

Childhood malnutrition is a particularly serious condition. Currently, as an average, the percentage of stunted children in Latin America and the Caribbean is 18% (stunting is defined as height below 2 SD of height for age of the reference population) and, in line with WHO data, when this occurs many other children also suffer from sub-optimal growth. Stunting is a reflection of a hostile environment and is strongly associated with impaired psychomotor development. This represents a continuing waste of human capital at a time of ever increasing demands for intellectual capacity and flexibility.

Latin America should not be considered as a homogeneous continent, because within it countries with quite different degrees of development and different ethnic backgrounds, rurality and industrialization coexist. These countries exhibit considerable differences in population and availability of natural resources. While some of them have been able to attain biomedical indicators and nutritional status almost comparable to those of the developed world, others have high proportions of a malnourished population with precarious health status that afflicts mainly their infantile population. According to at least two indicators (one of them indirect, the infant mortality rate, and the other direct, the proportion of stunted children) countries in the region may be classified as belonging to three groups: those which are more severely affected, an intermediate group, and those least affected. The most intensely affected countries are those of Central America and the Caribbean. These are in general small and a high proportion of their population is rural. The least affected countries are larger, and they form the southern part of the continent, although some small countries in Central America and the Caribbean have developed rather satisfactorily and may be considered part of this group (table 1 and fig. 1).

During the last decades a relative improvement in the nutritional status of preschoolers has become apparent, particularly among the South American countries. This is shown in figs. 2 and 3, which include the percentage of stunted children (under six years of age) in the countries of the region, which have carried out more than one survey during this period. A comparison of the results shows that, as an average, there has been a minor decrease in the Central American countries and a more pronounced decrease in the South American countries; this decrease is particularly evident in the case of Chile.

On the other hand, and according to data from FAO, an increase in energy and protein availability has been observed in almost all countries (expressed on a *per capita* basis) but this is still far from the levels observed in the developed countries (table 2).

FOOD PRODUCTION

Taken as a whole, the region may be considered as producing enough food to satisfy the needs of its population. Again, there are considerable differences between countries. Thus, for example, Argentina produces 14 million metric tonnes of wheat, most of which is exported. Nevertheless, the region has to import 10 million metric tonnes every year. The Central American countries (including Mexico) produce 3.4 million tonnes and have to import 2.3 million tonnes. South America (including Argentina) produces 20 million tonnes of grains but must import 8.5 million. In general, grain production (wheat, corn and rice), which provides between 70 and 80% of dietary energy, is deficitary in most countries, which must rely on growing imports of foodstuffs to satisfy their needs.

But in general, food production in the region has been increasing slightly over population growth (fig. 4).

In this way, the supply of foodstuffs (Food produced + imports – exports + stores) has been steadily increasing in Central America, the Caribbean, and South America (table 3).

Table 1. *Infant mortality and percentage of stunting in Latin America.*

Less affected countries	*Prevalence of stunting* (%)	*Infant mortality* (per thousand)
Chile	2.2	10
Argentina	4.7	22
Uruguay	4.6	17
Trinidad y Tobago	4.8	14
Barbados	7.0	14
Costa Rica	9.2	12
Jamaica	9.6	12
Panamá	9.9	22
Intermediate level		
Brazil	10.5	43
Paraguay	13.0	39
Venezuela	13.2	33
Colombia	15.0	33
Perú	15.9	46
Dominican Republic	16.5	34
Most severely affected countries		
México	22.8	38
El Salvador	23.1	39
Nicaragua	23.7	45
Guyana	23.7	49
Haiti	31.9	60
Ecuador	34.0	46
Bolivia	37.7	52
Honduras	39.6	45
Guatemala	57.7	49

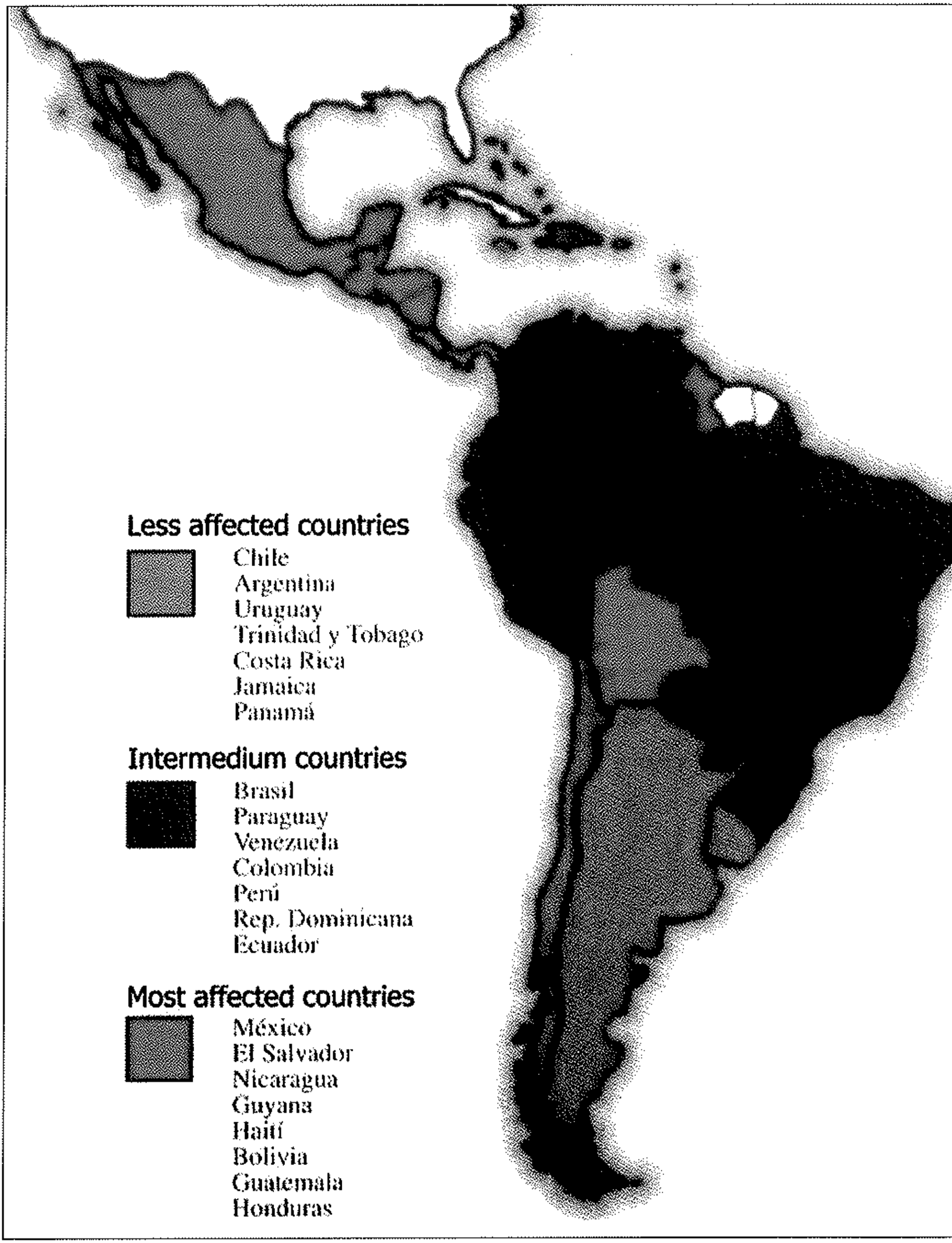


Fig. 1. Health and Nutritional Conditions of Children in Latin America.

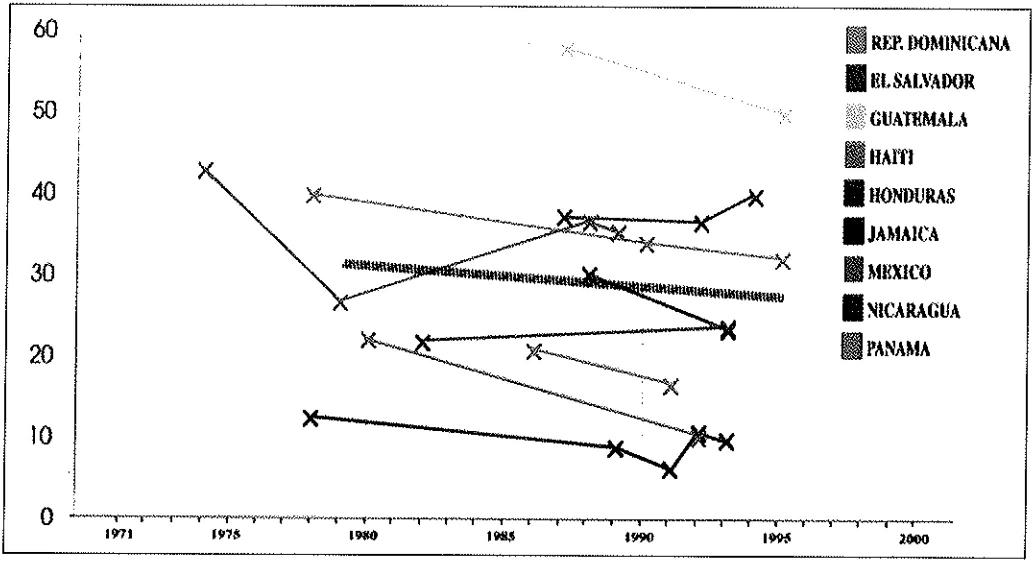


Fig. 2. Percentage of Children with Growth Retardation in Central American Children (0-6 years old).

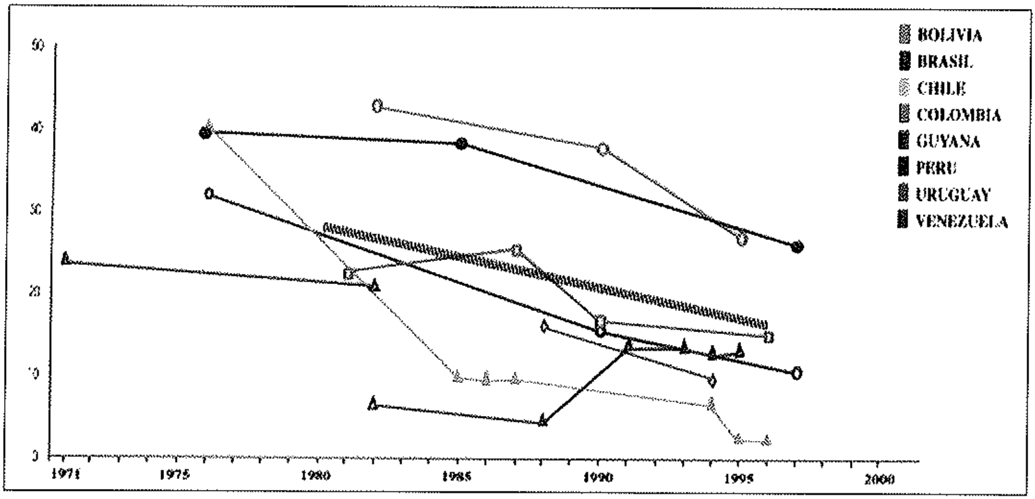


Fig. 3. Percentage of Children with Groiwth Retardation in Southed American Countries (0-6 years old).

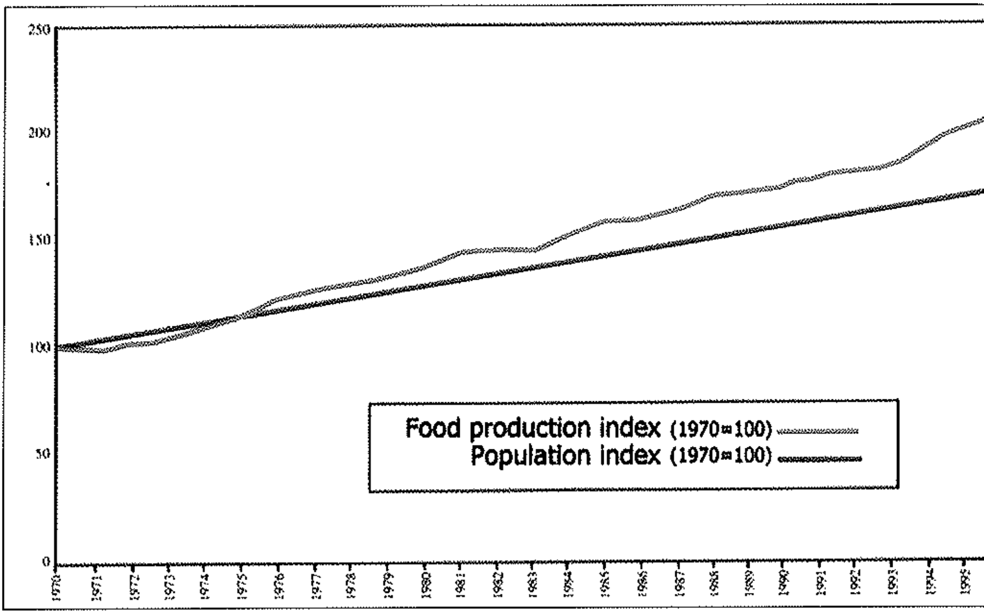


Fig. 4. Population and Food Production in Latin American.

Table 2. *Kilocalories: available per person and per day.*

	1961	*1970*	*1980*	*1990*	*1996*
Central America	2.383	2.565	2.908	2.914	2.943
South America	2.343	2.477	2.673	2.619	2.814
Developed countries	3.020	3.180	3.270	3.330	3.400

As illustrated by this table, despite the accelerated growth of the population, food production has slightly outstripped it and this, when added to the growing imports, has increased *per capita* food availability. However, it is important to keep in mind that these are averages and that these increments have not taken place in all countries. Thus, of the 25 countries in the region, *per capita* food production has increased in 13 while it has decreased in the remaining 12, which have had to resort to imports to cover the deficit. These

Table 3. *Total availability of foodstuffs in Latin America 1970-1996* (thousands of tonnes).

	1970	*1980*	*1990*	*1996*
Population	*258.620.000*	*330.084.000*	*404.161.000*	*448.041.000*
Prodution				
Total	409.666	597.646	795.521	965.586
Plant origin	368.815	534.774	720.353	870.567
Animal origin	40.851	62.872	75.168	95.019

12 countries are Peru, Ecuador, Honduras, Panama, Nicaragua, Cuba, Haiti, Barbados, Dominican Republic, Jamaica and Mexico.

This is especially worrying because the countries which have decreased *per capita* food production are those that have been more severely affected and have attained lower levels of economic development. For this reason, they have had to spend a larger share of their export earnings to bring in food for their population, but nonetheless their food security is unstable. In Haiti, for example, the cost of food imports exceeds the sum of all its exports. The Dominican Republic, Barbados, Cuba, Nicaragua, Panama and El Salvador must spend abroad between 60 and 30% of their total exports in food imports while Argentina, Chile, Uruguay and Brazil spend between 3 and 10% of their total exports for the same purposes, a situation that makes their food security far more stable.

The unstable food security of some countries became evident last year when El Niño struck and there were the results of the Asiatic economic crisis. The adverse meteorological conditions caused by El Niño had disastrous effects because the adverse weather conditions (copious rains, floods, storms, tornados, drought) that affected mainly the Central American countries, interfered with agricultural production, but also some South American countries such as Peru. The main consequence was a decrease in cereal production: as a consequence the Central American countries had to increase their purchases of food abroad and this further drained their foreign reserves. Some of them even had to appeal for international help, which is increasingly difficult to obtain as, according to FAO, world grain reserves have been below the minimal required for world food security for the last three years.

On the other hand, the economic crisis in Asia impacted negatively on these same Central American countries because most of them are exporters of

Table 4. *Grain imports by low income countries in 1998* (thousands of tonnes).

Countries	*Food imports*	
	Purchases in the grain markets	Food assistance
Bolivia	208	124.6
Cuba	1.443	6.5
Equador	512	9.5
Guatemala	740	39.8
Haiti	396	108.7
Honduras	379	32.1
Nicaragua	139	33.1
Dominican Republic	1.039	3.0

some of the commodities whose prices have been most affected, with a consequent decrease of earnings and a negative impact in their trade balances.

The volume of grain imports during 1998 by the countries with lowest levels of income and food shortages is shown in table 4.

SHORT-TERM PERSPECTIVES

Food production has been increasing at a steady rate and faster than population growth; it is possible that this tendency will remain unchanged in the near future. Although the speed at which the Latin American population has been growing has been decreasing, this growth rate still remains high.

Even taking into account this slowing growth rate, it has been estimated that the total population will grow by about 26% in the next 20 years, from the current 507 million to 685 million (table 5). It is important to keep in mind, however, that the greatest increases will occur in those countries that have been most affected by the recent unfavorable weather conditions and by the economic crisis.

If it is decided to reach a certain level of food security for the next 20 years, the countries in the region should increase food production by more that 30% during the same period of time; if the food security outlook is to be improved in those countries which are presently most affected, this

Table 5. *Population projections for the years 2000 and 2020* (in thousand) (ECLA).

Countries	Year 2000	Year 2020	Increase (%)
Argentina	32.686	40.857	22
Bolivia	8.329	13.131	37
Brasil	170.693	220.509	23
Chile	15.211	19.548	23
Colombia	42.321	59.756	30
México	98.881	130.196	25
Paraguay	5.496	9.335	42
Perú	25.662	35.518	28
Uruguay	3.337	3.907	15
Venezuela	24.170	34.775	31
Other countries	76.800	111.217	31
Total	*507.932*	*685.074*	*26*

target should be exceeded. Taking into consideration the realities prevailing in most of them, it is evident that a majority may attain this goal, simply by exploiting rationally their national resources. Yields per hectare for various cereals are much lower than those attained by the developed countries. To correct this situation it is necessary to make proper use of available land suitable for agriculture, and at the same time it becomes imperative to modernize the countryside using input intensive techniques, mechanization, planting two crops per year, decreasing the area of fields left fallow, applying fertilizers and pesticides as required, and planting high-yield seeds and strains resistant to plagues through genetic manipulation, etc.

It is also important to promote a better use of available water resources and to increase irrigated acreage. Proper water utilization requires building dams, irrigation canals and ditches, adequate diversion and distribution of river water for irrigation purposes, etc. In addition, deep wells with motorized pumps should be perforated to carefully tap underground reservoirs that may be recharged by rainfall or runoff from snow melting.

All these changes require strategic planning adapted to each country and considerable sectorial investment, a situation that few of these countries can afford. There is no doubt that the potential for food production in Latin America is considerable and that many countries in the region, provided that they implement adequate policies, may change from being net food importers to being net exporters (at least theoretically).

Food Demand

But it is not only necessary to produce more food: this must be available to those who need it most. In the less developed countries individuals become undernourished not only because they do not know what to eat, or because they do not have access to an adequate variety of food, but mainly because they lack the means to buy or produce an adequate daily diet for themselves and their families. In the developing countries there is a direct relationship between income and calories consumed. With higher incomes, energy consumption and the quality of the diet improves, associated with higher intakes of animal protein.

For this reason, a relationship can be observed between the GNP of the different Latin American countries, and the percentage of malnourished children, below 6 years of age (fig. 5).

In most Latin American countries, income distribution is very regressive, with a disproportionate concentration of income in a small percentage of the population. However, it is also true that in most countries there is not enough income to distribute. In the United States for example, the annual *per capita* amount spent to purchase food was approximately 2,600 US Dollars in 1995. This amount of money was greater than the total *per capita* income of most Latin American countries in the same year.

In the United States, the population spends as an average about 16.8% of its income on food. In Latin America, in its efforts to stave off hunger, the population is forced to spend on an average as much as 64% of its income on food. In our experience, an adequate diet should not require expenditure exceeding 30% of total income. When less than this amount is spent on food, the possibility of choosing what to eat becomes a reality. This constitutes a satisfactory index that income is reaching satisfactory levels. When income is low and food expenditures require 60% or more of the total income to avoid hunger, there is a loss of elasticity in the choice of food and individuals have to acquire the maximum amount of bulk at the minimum cost: this does not mean that the diet is satisfactory. Under these circumstances, people are not hungry but this does not mean that their diet is of good quality.

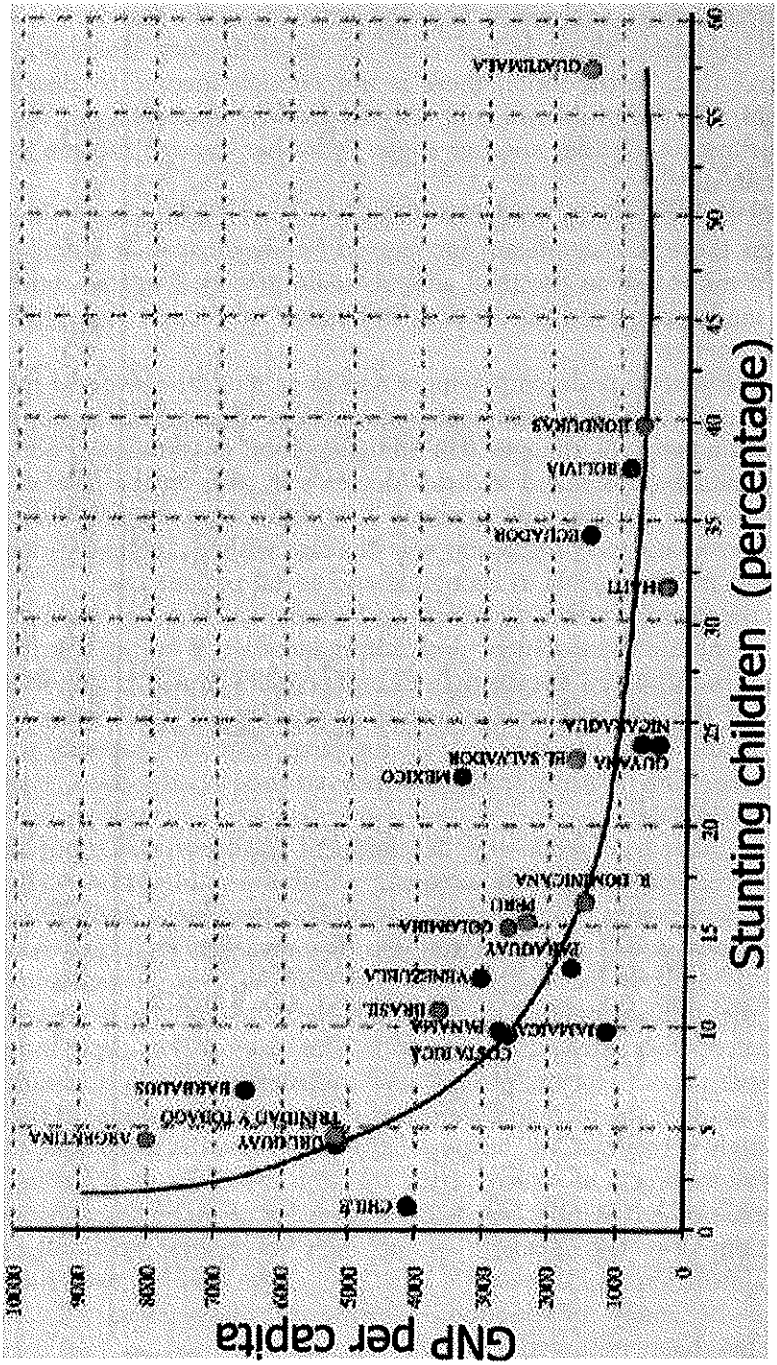


Fig. 5. Relationship Between Development Index and Percentage of Stunting Children.

From this short analysis, it is possible to conclude that in the Latin American countries there is not only an unsatisfactory distribution of income but that, furthermore, there is not enough income to distribute. This means that the problem is not only to produce enough food, but that it is important to consider another angle: "who has enough income to buy an adequate diet".

It will be difficult to eradicate malnutrition in Latin American countries unless there is a significant increase in family income. It is important to keep in mind that in the final analysis malnutrition is not so much the result of inadequate food production, but rather of poverty (fig. 5) and of underdevelopment.

Unemployment, underemployment and in general low levels of income are, in the end, the main causes of malnutrition. When income increases, this triggers a series of changes that stimulate food production. Food production depends on demand and this depends in turn on the level of economic and social development attained. It is difficult to imagine the opposite situation: that food production will increase without increased demand and without improvements in economic and social parameters.

It is therefore possible to conclude that the decrease of malnutrition requires economic development and, simultaneously, a better distribution of income. Both factors are strongly interdependent, but it is important to be aware of the fact that improvements in income are slow, because this requires, in the lower strata of society, the generation of a capacity to generate income. This in turn requires improvements in education, training, nutrition and health.

On the other hand, economic development requires that the population be healthy, educated and has adequate capabilities. Modern society has become very complex, and the demands on the knowledge and skills of its members grows constantly. Incorporation of individuals as useful members of society is unlikely if their environment deprives them of wellbeing and impedes the full expression of their genetic potential, or if they suffer impairment of their intellectual capacities. The result is that those individuals who suffer from chronic poverty and malnutrition are in a situation of inferiority *vis à vis* the increased demands of modern education and training.

If a high percentage of the population has been damaged and cannot become full members of society, there are no possibilities of achieving economic development. Under these circumstances, even if some economic improvement does take place, it is not likely to benefit the lower strata, where malnutrition and disease are most prevalent. This assertion has been confirmed by many observations. During the last decade, economic progress has been observed in Latin America but this has resulted in a widening of the gap between the highest and the lowest levels of income. Thus, while the poorest 20% of the population did not increase its income levels, the richest 10% increased its income by about 600 US Dollars on average.

What Should be Done?

As suggested by the preceding paragraphs, the Latin American countries are enmeshed in a vicious circle and perhaps the only way to break free of it is by protecting and caring for its human resources, stimulating the full expression of its genetic potential, and providing the best education and training possible, with the aim of transforming all individuals into useful members of society. If this takes place, the most deprived groups will accede to higher levels of income, and this in turn will stimulate the growth and development of the country. It is important to emphasize that the human resources of a country are the most important, albeit insufficiently recognized, factor behind social and economic development.

Protection of this invaluable resource is a difficult, long-term task where four main areas have to be considered: health, nutrition, sanitation, and education. Strategies have to be planned and adapted to develop the human resources available in relation to each of these four areas and to coordinate programs among the institutions, both governmental and private, concerned with their application. Individuals have to be protected from the moment they are born and, better yet, even before birth by means of adequate nutrition, sanitation, health care, education and proper housing. These aspects must be coordinated because they are interrelated and interdependent.

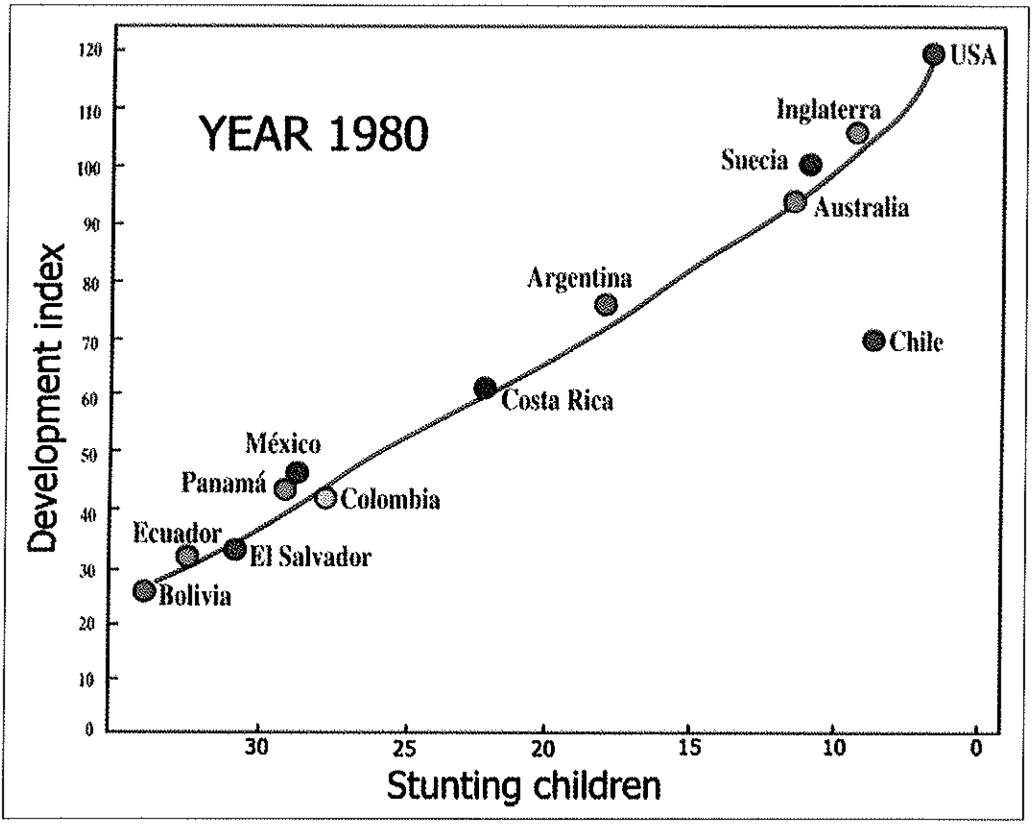
These programs involve the expenditure of considerable resources, and the ultimate decision to implement them rests at the political level. In a situation of underdevelopment, governments have many pressing priorities and political decisions on primary health care, nutrition, and elementary education for the poor receive low priority and are frequently postponed.

To face this reality requires a reorientation of the available resources, which is not easy for governments because this affects the interests of other segments of society that react by applying pressure on the government to delay change. Unfortunately, those who suffer from extreme poverty and malnutrition usually are not well organized, and lack the means to exert to the full their political rights. On the other hand, individuals who have lived in chronic poverty have very low expectations, and have a pessimistic and fatalistic approach to life. Hopelessness and the acceptance of their unsatisfactory living conditions become the rule. They become marginalised from the mainstream of society, and this perpetuates a situation that has been going on for generations: they are the descendants of families living in the same situation, and unless positive changes are implemented, their descendants will repeat this pattern: this is because they consider this their normal situation. Another negative factor operating against them is that the results of the programs that will improve significantly their lot usually take a long time to become apparent and policymakers need immediate results.

Despite this apparently bleak picture, there have been some positive experiences in Latin America that confirm what has thus far been stated. One of these is the case of Chile, a country which despite adverse circumstances has been able to decrease dramatically malnutrition and at the same time has been able to preserve its human resources, thus making possible economic and social progress at a later stage.

In the early sixties, Chile had one of the highest infant mortality rates in Latin America (120 per thousand); at the same time, it had the highest percentage of stunting among children under 5 years of age (46%). From then on, a progressive, steady improvement in the health and nutrition of infants and which preschool children took place, and this continues to date. Current biomedical indicators show that the country has some of the best indices in the region. A good proportion of this improvement was achieved at a time (1970-1987) during which the *per capita* Gross National Product (GNP) did not change substantially, and while poverty persisted almost unchanged. Fig. 6 shows a correlation between the development index (in which the degree of development of countries has been calculated applying indicators generated by the Institute of Social Development of the United Nations and which considers 80 different items) during 1987. It is possible to observe the correlation between the degree of development of different countries and the percentage of children under 6 years of age who are malnourished. It is evident that Chile does not follow this correlation, because its infantile population had an adequate nutritional status despite a low level of development.

It was later on that as a consequence of the improvement of its human resources Chile experienced its remarkable economic development and as a result, during 1987-1998, the percentage of the population living in poverty decreased from 40.7 per cent to 18.2 per cent. The infant mortality rate is now close to 9 per thousand and the percentage of stunted children is now 2.4 (fig. 7). These changes took place mainly at a time when *per capita* income had not increased substantially; they were caused by improving access to basic services such as health, nutrition, education, housing and environmental sanitation for most of the population and, especially, for the



Correlation between nutritional status of children below 6 yrs. of age and degree of development in selected countries. Note: degree of development has been calculated using an indicator developed by the Institute of Social Development of the United Nations, based on 80 different items. Lower numbers indicate less development.

Fig. 6. Percentage of malnourished children (0-6 years).

most vulnerable socio-economic groups. Most calculations of income distribution do not take into consideration the economic value of transfers in the form of services and goods that governments make through health, education, housing, sanitation, nutrition, etc. I think that this is a mistake, because many of these have a greater impact on quality of life than direct increments of income.

In agreement with this policy, the health authorities organized a national health infrastructure for primary health care which in just 30 years was able to provide free coverage to the low income groups. During this time, coverage was not only extended but also made more effective. At the same time,

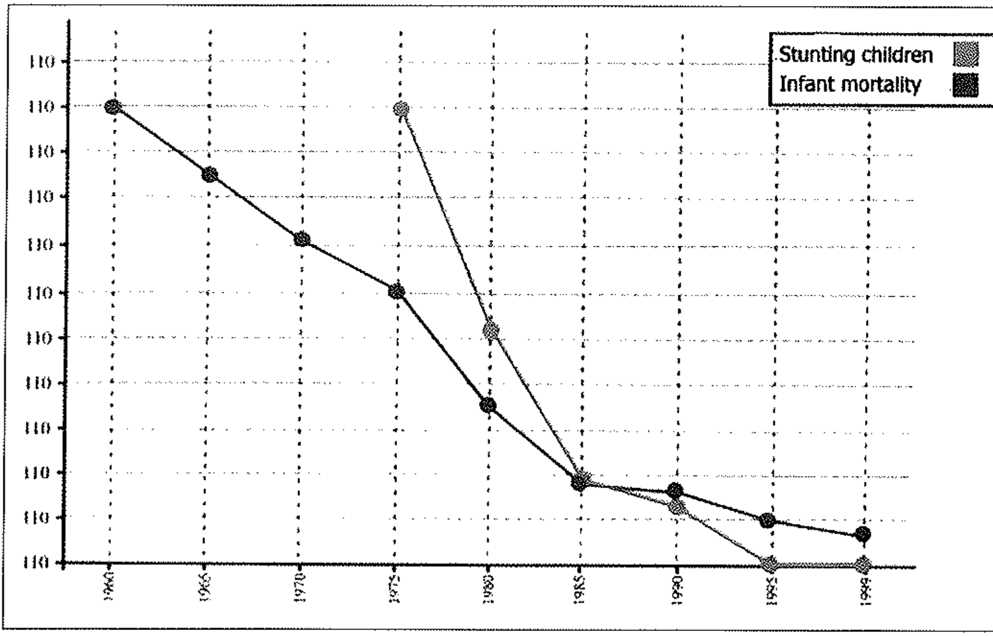


Fig. 7. Evolution of Infant Mortality and Stuning Children in Chile.

its personnel developed an attitude of service and a commitment to the community, whose respect they have earned. The population, in turn, has become aware of its rights and responsibilities in relation to health care. Thus, medical consultations during pregnancy have increased considerably, 98% of births take place in hospitals, and an estimated 95% of all children are regularly immunized. As a consequence, the incidence of diseases such as measles and whooping cough has declined considerably and poliomyelitis and tetanus neonatorum have been eradicated. Regular health check-ups have become routine and provide weight-for-age data about more than 90% of all preschool children throughout the country, who are examined every 3 months.

Programs of nutritional intervention were implemented through the National Health Service. This included the free distribution of powdered milk to every infant up to 2 years of age and weaning foods for children between 2 and 5 years of age. The program also included powdered milk distribution to pregnant and nursing mothers (table 6).

The food was distributed through the primary health care centers and served as motivation for other health activities, such as nutrition education

Table 6. *Food distributed monthly by the national health service to children and mothers.*

Group	Product	Amount (kg/mo)	Composition per 100g calories	protein (g)
Children				
0-5 mo	Milk, 26% fat	3	496	27
6-23 mo	Milk, 26% fat	2	496	27
2-5 yr	Weaning food	1.5	420	20
Women				
Pregnant	Milk, 12% fat	2	410	31
Nursing	Milk, 12% fat	3	496	27

and promotion of breast feeding. Thus, food distribution has been extremely important not only from the nutritional point of view but also as a mechanism to attract mothers to the health system.

In relation to education, elementary education received special emphasis with the aim of decreasing illiteracy, which used to be close to 30%. The incidence of illiteracy is only 3% now and 89% of children complete eight years of elementary education. To achieve these accomplishments it was important to improve the school feeding programs as a mechanism to prevent school desertion.

Another important decision was to extend the education and nutrition programs to the preschoolers. The reason was that a number of studies indicated that extreme poverty and malnutrition cause definite damage to the physical and intellectual capabilities of individuals. This damage is the result not only of malnutrition but of other negative factors inherent in chronic poverty. Under this program, a network of day-care centers for children two to six years of age was created. In these centers, under the care of specialized personnel, children receive all their daily nutrient requirements while at the same time they undergo specialized psychomotor and affective stimulation. This program has proved to be effective in preventing sociobiological damage and improving school performance later on.

Another program had to be implemented for homeless and troubled children designed to provide care in live-in centers for children of 2 to 12 years of age. These include orphans, abandoned children, and those who display maladjusted behavior. The aim was to restore the child to a situation that encouraged normal behavior, to combat child vagrancy, and to improve life conditions. The program has been extended and improved through the building of new centers and now covers some 60,000 children.

Last but not least, sanitary conditions have improved considerably. In 1974 a high percentage of the population lived in areas of extreme poverty that lacked running water and sewerage systems. Inadequate sanitation adversely affects child nutrition and increases the incidence of gastrointestinal and other infections. Improperly diluted, contaminated infant formula bottles were one of the main contributors to the early appearance of malnutrition, which at one stage in the evolution of the country appeared as early as the third month of life, with its associated risk of death. A national program was implemented to change this situation. Each family living in an urban area was provided with a brick-and-timber unit which included a kitchen, a bathroom, and an outdoor sink: the bathroom included a lavatory, a flush toilet connected to a sewerage system, and a shower. A geyser supplied hot water. In 1960 only 40% of urban dwellers had access to safe drinking water in their homes and only 35% had connections to an adequate sewerage system. At present, 99% of the population has access to drinking water and 89% live in houses connected to sewerage systems. There is no doubt that the resultant improvements in sanitary conditions have been important factors in the decrease of malnutrition and in the health conditions now prevalent in the country.

In addition, there are a wide variety of housing programs specially designed for low-income families which provide special subsidies such as low interest loans and long periods for payment. This has resulted in a noticeable decrease of the housing deficit and improvements in housing quality.

Finally, in 1978 Chile changed its economic model from a planned, centralized economy to an open, free market-oriented, liberal economy. As a result, GNP has increased during the last 15 years at rates between 7 and 9% a year. Total exports have expanded during this period from 1.4 billion US dollars to 16 billion. There is no doubt that this growth is explained by a number of factors but it is also possible to postulate, although it is difficult to prove, that the change and improvement of the quality of human resources has played an important part in this process. As an additional parameter of this change it is worth noting that the average 18 year-old Chilean male is 11 centimeters taller than his homologue of 30 years ago: this represents the improved expression of the genetic potential of the population. It is also possible to assume that mental impairment due to malnutrition and lack of proper stimulation has also been prevented.

REFERENCES

CEPAL/ECLAC, *Panorama de la Agricultura de América Latina y el Caribe en las Ultimas Décadas* (1997).

FAO, *Prospects Related for the World Food Situation on the Threshold of the 21st Century*, June, 1997.

FAO/SMIA, *Perspectivas Alimentarias*, N° 2, Roma, Abril, 1998.

FAO/SMIA, *Cosechas y Escaseces Alimentarias*, N° 1, Febrero, 1998.

Mönckeberg, F., *Checkmate to Underdevelopment* (Editorial Gabriela Mistral, Santiago, Chile, 1974).

Mönckeberg, F., *Crear para Compartir. Compartir para Segui Creando* (Editorial Andrés Bello, Santiago, Chile, 1980).

Mönckeberg, F., *Jaque al Subdesarrollo Ahora* (Ediciones Pedagógicas Chilenas S.A., Santa Magdalena 187, Providencia, Santiago, Chile, 1994).

Mönckeberg, F., 'Food and World Population: Future Perspectives' in Philip M. Hauser (ed.), *World Population and Development* (Syracuse University Press, 1997).

Mönckeberg, F., 'Prevention of Malnutrition in Chile', in A. Bendich and R. Deckelbaum (eds.), *Preventive Nutrition* (Umana Press Inc. 999 Riverview Drive, Suite 208, Totowa, New Yersey, 1997).

UNICEF, *The State of the World's Children, with its Focus on Nutrition* (1998).

United Nations, ACC/SCN, *Third Report on the World Nutrition Situation* (December, 1997).

World Bank, *Sector Strategy for Health, Nutrition and Population* (November, 1997).

World Health Organization, *The World Health Report 1988.*

III.

TECHNOLOGICAL ASPECTS OF FOOD PRODUCTION AND HUMAN NUTRITION

PHYSIOLOGICAL LIMITS TO THE IMPROVEMENT OF CROP YIELDS

LLOYD T. EVANS

INTRODUCTION

Although our primary focus for this study-week is on the needs of the developing world, we also need to consider food production at the global level. The developing countries as a whole encompass almost 80% of world population, but they have only 52% of the world's arable land, producing 55% of the world's cereal grain. They are therefore having to import an increasing amount of grain each year, which is projected to almost double by the year 2020 AD. Consequently, I shall confine my discussion to the global level, although, in the words of the Brundtland Commission report: 'The Earth is one, but the world is not'.

THE IMPORTANCE OF CROP PLANTS TO WORLD FOOD SUPPLY

The most recent World Food Survey by the FAO (1996) indicated that about 84% of digestible energy in the world's diet (and 90% of that in developing countries) comes *directly* from crop plants, as well as some of the remainder *indirectly* from feed crops. If one takes the FAO production statistics for all food items, converts them to edible dry weight, and subtracts the amount used for animal feed and other purposes, the residual dry weights for human consumption yield dietary contributions similar to those from the World Food Surveys (Evans, 1998), but slightly overestimated because of non-allowance for alcoholic beverages (2.4%) and vegetable oils and fats (8.2%). Such estimates can be made annually whereas the World Food Surveys are only made every 10 years or so.

On this basis the cereals currently provide 54% of global dietary dry weight directly (44% from wheat and rice alone), to be compared with

51.2% of dietary energy supply (DES) and 47.2% of the protein. The two sugar crops contribute 8% of dietary dry weight (c.f. 8.8% of DES), compared with only 3% from the legume pulses. Root and tuber crops now contribute only 5% of DES, and vegetables and fruit only 4% for the world as a whole, hence my focus on the cereals in what follows. Animal products contribute 16% of DES and 35% of protein to the world's diet, but only about 10% of energy and 24% of protein to that of the developing countries. Fish contribute only 1% of energy but 5.9% of the protein. The loaves are now far more important than the fishes, and the world's food supply is highly dependent on a small number of staple crops, especially cereals.

ROUTES TO GREATER CROP PRODUCTION

Several routes to greater crop production could increase world food supplies:

1. Increase in the area of arable land.
2. Increase in yield per hectare per crop.
3. Increase in the number of crops per hectare per year.
4. Displacement of lower by higher yielding crops.
5. Reduced post-harvest losses.
6. Replacement of cash crops by food crops.
7. Replacement of feed crops by food crops.

(1) Increase in the area of cultivated land has been the main route to greater food production throughout human history, until the world population reached 3 billion in 1960 (figure 1). Since then the arable area has hardly changed, declines in the West being slightly exceeded by increases in Latin America and Africa. This is not because the world has run out of arable land, since several estimates suggest that the present area could be almost trebled, albeit with land of poorer quality, more vulnerable, less accessible or under vegetation we wish to preserve. Of present arable land, almost 1% is lost annually to erosion, degradation and urban sprawl. Urbanization is not only the biggest cause of loss, but also takes mostly prime agricultural land (Buringh & Dudal, 1987).

(2) Since 1960 it is increase in yield per hectare per crop, especially among the cereals, that has allowed food supply to keep pace with population growth at the global level. Indeed, average cereal yields have increased in a 1:1 proportion with population (figure 1), just as arable area appears to have done before 1960. The close proportional relation between world population and average cereal yield since then merits further analysis. The

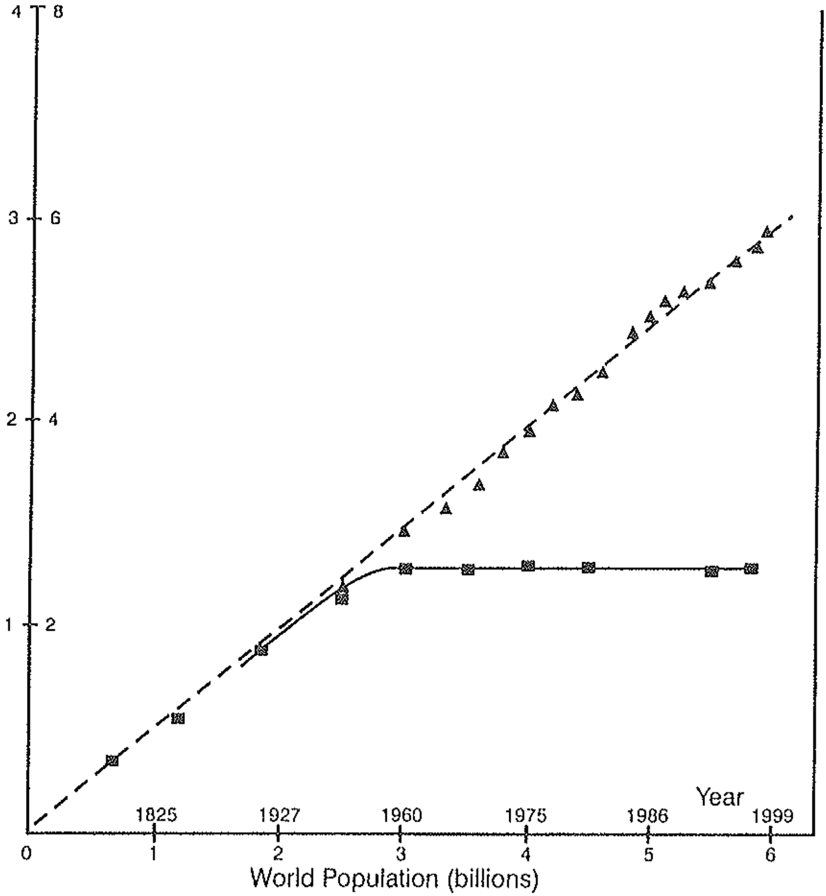


Fig. 1. The relation between world population (- - - -) and arable area (▨) and average cereal yield (▲). Data from FAO Production Yearbooks and from Evans (1998).

improvement in average food supply per head of 9.5% per year since 1969/70 should have resulted in some upwards curvature of the relation, which has presumably been counterbalanced by the rising proportion of the world population in the developing countries. The linear relation may, therefore, be fortuitous.

(3) Increase in the number of crops per hectare per year, often referred to as intensification, has made a significant additional contribution to increased food production, particularly in warmer areas where irrigation is available in the dry season. Alexandratos (1995a) estimates that only 13%

of the increase in food production by 2010 AD will come from greater cropping intensity, but global warming could make it more significant, provided that irrigation is extended.

(4) The displacement of lower by higher yielding or more reliable crops has been going on for thousands of years – hence the present dominance of wheat, rice and maize – and contributes to the rise in average crop yield. However, between 1970 and 1991 for the world as a whole, the arable area planted to the three staple cereals increased by only 9% while that planted to root and tuber or pulse crops scarcely changed, whereas production of the three staple cereals increased by about 70% each compared with only 13% for roots and tubers and 9% for pulses. Thus, the increasing dominance of the cereals in world food supply in recent years has come much more from their faster improvement in yield than from a real displacement of non-cereal crops.

(5) Although any reduction in post-harvest losses would be helpful, it now appears that the scope for improvement is far less than earlier references to it as 'the soft third option' implied.

(6) Cash crops remain an important – often the only – source of income for small farmers. Moreover, they occupy only 10% of arable land and, especially in the case of tree crops in the humid tropics, play an important role in soil conservation.

(7) Almost half (44%) of our present grain production is fed to livestock. If all feed grain became human food, our present agriculture could support a population of almost ten billion, and the malnourished 800 million or so of us could be adequately fed. But without what Amartya Sen (1981) refers to as 'entitlement', that will not happen. This issue highlights the problems of estimating an upper limit to the world population that can be fed. It is difficult enough when based on needs, and virtually impossible when based on wants.

However, the preceding discussion does highlight the crucial role of further increases in yield per crop in meeting the food needs of future populations.

ROUTES TO INCREASED YIELD

The rise in crop yield is often partitioned between plant breeding and agronomy by comparing the yields of old and recent cultivars under modern crop management to estimate the genetic advance, and allocating the residue to advances in agronomy. In many such comparisons breeding and agronomy are deduced to have contributed about equally to the rise in yield (Evans, 1993). With potatoes in the USA, however, the average yield has increased sixfold since 1920 without any rise in genetic yield potential (figure 2), because the plant breeders have focused on earliness and quality instead (Douches *et al.*, 1996). At the other extreme is cotton in the USA in which, for a period when agronomic inputs were limited by legislation, the rise in genetic yield potential exceeded the rise in yield (Bridge & Meredith, 1983).

Rather than allocating credit for the rise in yield between agronomy and plant breeding, it is the synergistic interactions between them that need to be emphasized.

(1) *Advances in agronomy* and crop management have contributed greatly to the rise in crop yields since 1960, e.g. in the formulation and use of fertilizers, herbicides, regulants, adjuvants and irrigation water. To a large extent the Green Revolution was driven by the availability of cheaper nitrogenous fertilizers, and made possible by the development of more effective weed control. The former made the breeding of shorter statured cultivars essential, to avoid lodging, and in turn the dwarf cereals required more effective weed control to realize their full advantage. It was the synergism between breeding and agronomy that was so potent.

Nitrogenous fertilizers also interact with plant breeding objectives in many other ways. They can be a surrogate for selection for faster early growth. They made selection for faster photosynthesis unnecessary by raising the N content of the leaves and their CO_2 exchange rate (CER) in parallel. When applied late they aid the development of more florets and delay the mobilization of N out of the leaves into the storage organs, making it possible to select for more prolonged leaf photosynthesis and grain storage.

(2) *Protective crop science* plays a crucial role in maintaining soil fertility in the face of erosion and genetic resistances as pests and pathogens evolve new biotypes. Having well-defined goals, it has an excellent record of success, and contributes greatly to the sustainability of farming systems. An indication of its impact relative to that of breeding for higher yield potential can be seen in the comparison of the yields of an historical series of CIMMYT spring wheat cultivars when grown with or without protection from leaf rust by fungicide (Sayre *et al.*, 1997). Although lumbered with the unexciting title of ‘maintenance research’, breeding to maintain resistances to pests and diseases possibly contributes more than breeding for higher yield potential towards keeping crop yields in step with world population. In agriculture there has never been a golden age when moth and rust did not corrupt!

Recent estimates by Oerke *et al.* (1995) suggest that average losses to pests, diseases and weeds for 8 major crops amount to about 42% of poten-

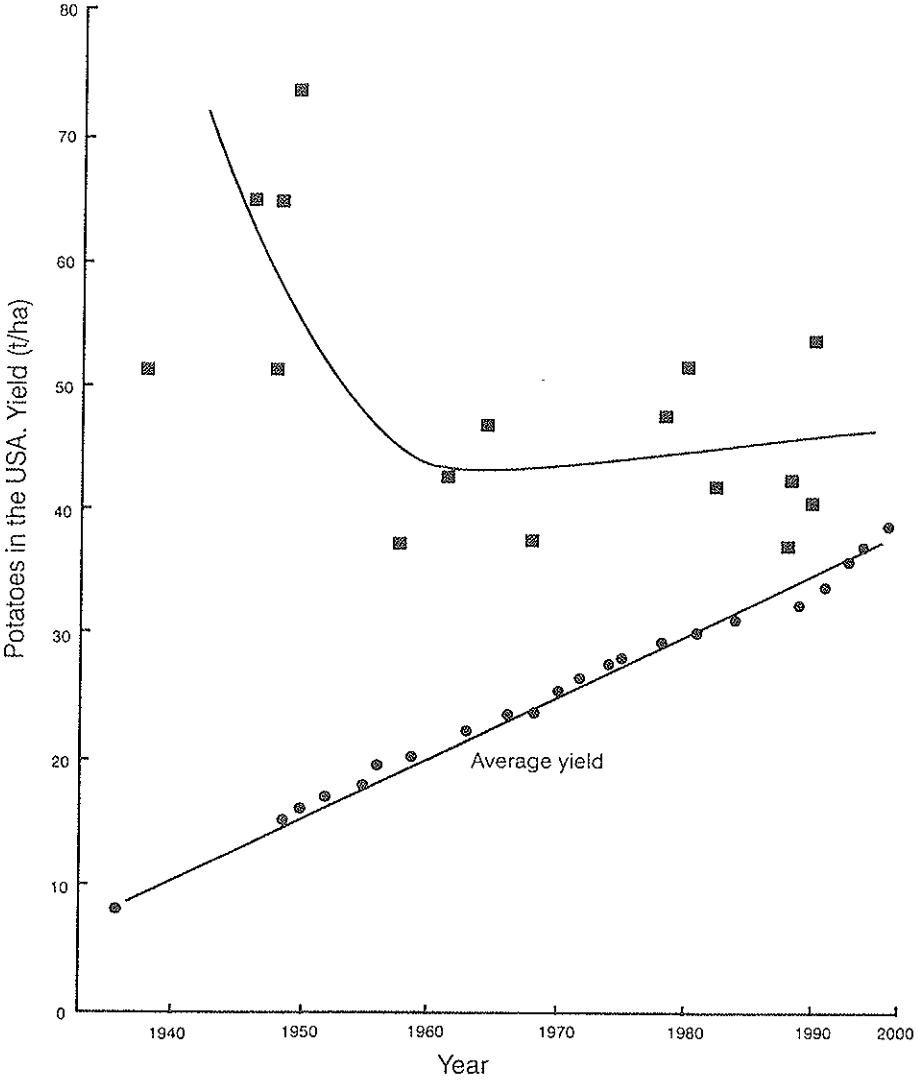


Fig. 2. The change in average yield of potatoes in the USA (●) in relation to that in the yield potential of leading cultivars by their year of release (▨). Data of Douches *et al.* (1996) and FAO Production Yearbooks.

tial production, even higher than the earlier estimate of 34.9% loss overall (Cramer, 1967). Thus, these comprehensive estimates provide no evidence of overall gain in our conflict with these other organisms, and no global eliminations to be compared with smallpox.

(3) *Reduced loss from environmental stresses* is also an important goal for both plant breeding and agronomy. Both have contributed to the reduction of stresses due to soil toxicities and nutrient imbalances, for example. *Avoidance* of injury by drought, heat or cold through the modification of flowering time or crop duration has been highly effective. *Tolerance* of particular stresses has also been improved in some cases, e.g. in modern maize hybrids to cool nights, drought or low N supply (Nissanka *et al.*, 1997).

While such selection has much in common with selection for improved resistance to pests and diseases, the criteria for selection are often more complex, even obscure. Similarly, such selection may overlap with that for greater yield potential. With temperate maize, for example, a major component of selection for yield potential has been selection for the ability to withstand the stresses of being planted more densely in rows progressively less than the width of a horse apart.

(4) *Increase in genetic yield potential* ranks high in most plant breeding programs. The yield potential of a cultivar is the yield it reaches when grown in environments to which it is adapted, with nutrients and water non-limiting, and with pests, diseases, weeds and, other stresses effectively controlled (Evans, 1993). Its improvement is often sporadic, e.g. following the introduction of the dwarfing genes in wheat and rice, but in the longer term it tends to be more or less linear, as with Pioneer maize hybrids in the USA and CIMMYT spring wheats. This may reflect an empirical but progressive assembling of 'productivity genes', possibly reflecting in turn the progressive broadening of their land race backgrounds (Evans & Fischer, 1999).

The rate of increase in yield potential of Pioneer maize hybrids and CIMMYT wheats (73 and 67 kg ha^{-1} y^{-1} respectively) is currently equivalent to more than 1% per year, to be compared with rather less than 2% increase per year in current world agricultural production (Alexandratos, 1995b). The continuing improvement of yield potential in these crops is clearly playing a significant role in matching yields with population increase. Although the rise in yield per crop for IRRI rices has not been so clear in recent years, the emphasis on earlier-maturing varieties has been associated with increases in yield per day, which can be just as important given the multiple cropping potential of the irrigated tropics.

Although yield potential is measured under highly favorable conditions on experiment stations, Bell *et al.* (1995) have shown that the varietal rankings are commonly maintained on farm and with farmer management. They may also be maintained in adverse years and at low N supplies. Not until yields are reduced to about 30% of potential is the advantage of the modern wheats lost (Laing & Fischer, 1976). Thus yield potential rankings of cultivars can be highly relevant to a substantial proportion of farms in the areas to which the cultivars are adapted.

THE PHYSIOLOGICAL BASIS OF HIGHER YIELD POTENTIAL

(a) *Trends to date*

Physiological comparisons of recent cultivars with older, lower-yielding ones, extended where possible to include the wild progenitors of the crop, are valuable in indicating not only what processes have been changed, or 'improved', but also those which have not been modified by selection so far.

Among the small grain cereals such as wheat and rice, by far the most significant change to date has been the rise in the harvest index, i.e. in the proportion of crop dry weight that ends up in the grain. This began even before the dwarfing genes were introduced, but accelerated after that. In general, harvest index increases as height (and stem weight with it) is reduced, thereby freeing photosynthetic assimilates for investment in floret development and grain growth rather than in stem growth. Dwarf wheat and rice varieties have long been known, but conferred no advantage until weed control became more effective. Among both CIMMYT spring wheats and English winter wheats the rise in yield potential bears a 1:1 relation with the rise in harvest index (Evans & Fischer, 1999). One corollary of this finding is that the higher yielding cultivars have not grown any faster than the older ones, despite many references to them as 'wonder wheats' and 'miracle rices'. It is simply that, as fertilizers improved their access to nutrients while herbicides freed them from the need to have tall stems and many tillers, progressively more of the crop dry weight could be allocated to the inflorescence and then to the grains, thereby increasing yield potential.

However, there is obviously a limit as to how high the harvest index can rise. Although this will depend on crop duration and other factors, the harvest index of cereals is unlikely to rise much beyond 65%. Since modern cultivars already reach up to 55%, there is some, but only limited, scope for further improvement along that path, and the rise in harvest index appears to be slowing.

North American hybrid maize has followed a quite different path to higher yield potential. In Duvick's (1992) comparisons of Pioneer maize hybrids spanning six decades, plant height has hardly changed. However, modern fertilizer and weed control techniques have allowed the crop to be planted at progressively higher densities. The increase in yield potential has come from selection for greater tolerance of the adverse effects of the denser planting on ear and grain development. Recent hybrids have more ears per plant, but smaller tassels and more acutely inclined upper leaves which allow more light to reach the leaves subtending and supplying the young female inflorescences, which probably increases grain set and early grain growth and survival. They also have reduced interval between anthesis and silking.

All these changes, in both wheat and maize, emerged from sustained empirical selection for yield. Only after their recognition from historical variety comparisons were they then used as selection criteria, as in the case of anthesis-silking interval in tropical maize (e.g. Edmeades *et al.*, 1997).

(b) *Some future possibilities*

Extrapolation of the 1:1 relation between world population and average cereal yield in figure 1 indicates that the average will have to reach almost 4 tonnes per hectare by 2020 AD, and 5 t ha^{-1} by 2050 AD compared with 3 t ha^{-1} in 1997. Even existing cultivars could certainly reach those levels if given sufficient fertilizer, irrigation and crop protection.

Agronomic intensification and innovation will certainly continue with more and more nutrients and a greater range of other inputs applied to crops in better forms, at better times and with better placement, with more effect and less adverse side effects. Precision farming will aid this, but at some cost. Crop protection will become more comprehensive and integrated.

Empirical selection for greater yield potential will continue to be effective and will, with the help of periodic comparisons of old and new cultivars, reveal trends to be amplified by specific selection, as in the past for a shorter interval between anthesis and silking, and for more prolonged photosynthetic activity ('stay green') by leaves of maize.

A current example of such trends is illustrative. Among Pima cotton cultivars bred for high yield in warm climates when grown with irrigation, it was noticed that the stomata remained more open in the afternoon in more recent cultivars. Greater stomatal conductance and the enhanced leaf cooling associated with it were shown to be associated with fruiting prolificacy during the hottest period of the year, and with yield, but not with any enhancement of photosynthesis (Radin *et al.*, 1994). The availability of irrigation has allowed the plant breeders to trade greater water use for greater boll set and growth without any awareness that this was a promising route to higher yields.

It now appears that a similar trend has been associated with empirical selection for higher yield in CIMMYT's spring wheat breeding program, in which comparisons of historical series of cultivars reveal a high correlation between stomatal conductance and yield (Fischer *et al.*, 1998; Lu *et al.*, 1998). As a result, canopy cooling, which is easily measured, can be used as a specific criterion for further selection for yield potential in well-watered conditions.

Greater stomatal conductance could be associated with greater maximum rates of photosynthesis and crop growth, but only the former of these was found by Fischer *et al.* (1998). Across many comparisons of old and new cultivars of many crops there are only sporadic suggestions of an increase in the *maximum* CO_2 exchange rate (CER) being associated with increase in yield potential (Evans, 1993). On the other hand there are many examples of CER declining more slowly from its maximum, in modern cultivars, e.g. in soybeans. In some cases this may simply reflect the greater demand for assimilates, because the photosynthetic rate is highly subject to down-regulation. Moreover, the effect of any selection for higher maximum CER would have been dwarfed by the great impact of nitrogenous fertilizers on leaf photosynthesis, and by their breaking of the usual trade-off between leaf area and CER.

I have been sceptical of hopes of progress in selecting for greater photosynthetic capacity, i.e. maximum CER, while recognizing that there is ample scope for reducing the down-regulation of CER by increasing the internal demand for assimilates, and certainly for extending the duration of photosynthetic activity. Whether rubisco, the central enzyme of CO_2 fixation, which is often rate-limiting in spite of comprising 20-25% of leaf protein, can be genetically engineered to become a less 'feeble and confused catalyst', as one biochemist has referred to it, has yet to be seen. However, the fact that it has undergone extremely slow change in the course of evolution (Runnegar, 1991), and that both major variants of photosynthesis, the C_4 and CAM pathways, involve solutions which get around the limitations by rubisco, suggest that its re-engineering would be a quite remarkable feat.

SOME FUTURE PROBLEMS

Several trends will make the task of increasing crop yields more difficult:

1. Environmentalist and other pressures against *both* further intensification of agriculture and extension of the arable area.

2. The accelerating loss of our best agricultural land to urbanization: the number of urban dwellers is projected to rise from one third of three

billion in 1960 to two-thirds of eight billion by 2020 AD, i.e. from 1 billion to 5 billion.

3. The prospect of global warming, which modelling studies suggest is likely to reduce crop yields, especially at the lower latitudes where much population growth will occur (Rosenzweig & Hillel, 1998).

4. Lack of economic incentives in Europe and North America to increase their already high average yields (4 t ha^{-1}) still further.

5. A decline in the expansion of irrigation in the face of greater competition from industry and urban areas for increasingly scarce sources of water.

CONCLUSION

The 1:1 increase in the average cereal yield of the world as the population has increased since 1960 (fig. 1) shows no sign yet of an approaching limit. It is more Boseruppian than Malthusian, in that the rise in cereal yields would seem to be driven by that in population. In many developing countries, however, the rise in food production is not keeping abreast of population growth, with the consequence so clearly foreseen by Robert Malthus just 200 years ago, namely that 'This difficulty (of providing enough food) must fall somewhere and must necessarily be severely felt by a large portion of mankind'.

What Malthus could not have foreseen was that food supply could increase geometrically to match population growth as a result of the application of scientific understanding and methodology to agriculture. There is no indication that this process is exhausted, indeed a further extension of irrigation and input use, were it economically viable, could see yields raised substantially. Present world record yields of our crops are far beyond the average yields, 6 times so in the case of maize and wheat. World average yields could never approach them, but they do indicate that even our present cultivars have the capacity to yield far more. With further innovations in agronomy and continued plant breeding for resistance or tolerance to pests, diseases and climatic stresses, with or without further improvements in yield potential, average cereal yields should be able to reach 4 t ha^{-1} by about 2020 AD and, less confidently, 5 t ha^{-1} by 2050 AD. If the world population continues to increase beyond 2050 AD, we shall require all our agronomic ingenuity, our plant breeding skills and our understanding of plants to meet the challenge, and the greatest of these is understanding. What we do not yet understand may be our most vital resource.

REFERENCES

Alexandratos, N. (ed.) (1995a): *World Agriculture: Towards 2010. An FAO Study* (FAO, Rome/ Wileys, Chichester).

Alexandratos, N. (1995b): 'The Outlook for World Food and Agriculture to Year 2010', in N. Islam (ed.), *Population and Food in the Early Twenty-first Century: Meeting Future Food Demand of an Increasing Population* (IFPRI, Washington D.C.), pp. 25-48.

Bell, M.A., Fischer, R.A., Byerlee, D., and Sayre, K. (1995): 'Genetic and Agronomic Contributions to Yield Gains: A Case Study for Wheat', *Field Crops Research*, 44, pp. 55-65.

Bridge, R.R., and Meredith, W.R. (1983): 'Comparative Performance of Obsolete and Current Cotton Cultivars', *Crop Science*, 23, pp. 949-952.

Buringh, P., and Dudal, R. (1987): 'Agricultural Land Use in Space and Time, in M.G. Wolman and F.G.A. Fournier (eds.), *Land Transformation in Agriculture* (Wiley, New York), pp. 9-43.

Cramer, H.H. (1967): *Plant Protection and World Crop Production* (Bayer, Leverkusen).

Douches, D.S., Maas, D., Jastrzebski, K., and Chase, R.W. (1996): 'Assessment of Potato Breeding Progress in the USA over the Last Century', *Crop Science*, 36, pp. 1544-1552.

Duvick, D. (1992): 'Genetic Contributions to Advances in Yield of U.S. Maize', *Maydica*, 37, pp. 69-79.

Edmeades, G.O., Banziger, M., Elings, A., Chapman, S.C., and Ribaut, J.M. (1997): 'Recent Advances in Breeding for Drought Tolerance in Maize', in M.J. Kropff *et al.* (eds.), *Applications of Systems Approaches at the Field Level*, 2, pp. 63-78.

Evans, L.T. (1993): *Crop Evolution, Adaptation and Yield* (Cambridge University Press, Cambridge).

Evans, L.T. (1998): *Feeding the Ten Billion: Plants and Population Growth* (Cambridge University Press, Cambridge).

Evans, L.T., and Fischer, R.A. (1999): 'Yield Potential: its Definition, Measurement and Significance', *Crop Science* (in press).

FAO (1996): *The Sixth World Food Survey* (FAO, Rome).

Fischer, R.A., Rees, D., Sayre, K.D., Lu, Z., Condon, A.G., and Larque-Saavedra, A. (1998): 'Wheat Yield Progress Associated with Higher Stomatal Conductance and Photosynthetic Rate, and Cooler Canopies', *Crop Science*, 38, pp. 1467-1475.

Laing, D.R., and Fischer, R.A. (1977): 'Adaptation of Semi-dwarf Wheat Cultivars to Rainfed Conditions', *Euphytica*, 26, pp. 129-139.

Lu, Z., Percy, R.G., Qualset, C.O., and Zeiger, E. (1998): 'Stomatal Conductance Predicts Yields in Irrigated Pima Cotton and Bread Wheat Grown at High Temperatures', *Journal of Experimental Botany*, 49, pp. 453-460.

Nissanka, S.P., Dixon, M.A., and Tollenaar, M. (1997): 'Canopy Gas Exchange Response to Moisture Stress in Old and New Maize Hybrid', *Crop Science*, 37, pp. 172-181.

Oerke, E.C., Dehne, H.W., Schohnbeck, F., and Weber, A. (1995): *Crop Production and Crop Protection: Estimated Losses in Major Food and Cash Crops* (Elsevier, Amsterdam).

Radin, J.W., Lu, Z., Percy, R.G., and Zeiger, E. (1994): 'Genetic Variability for Stomatal Conductance in Pima Cotton and its Relation to Improvements of Heat Adaptation', *Proceedings National Academy of Science USA*, 91, pp. 7217-7221.

Rosenzweig, C., and Hillel, D. (1998): *Climate Change and the Global Harvest* (Oxford Univ. Press, Oxford).

Runnegar, B. (1991): 'Nucleic Acid and Protein Clocks', *Philosophical Transactions of the Royal Society of London*, B 333, pp. 391-397.

Sayre, R.D., Rajaram, S., and Fischer, R.A. (1997): 'Yield Potential Progress in Short Bread Wheats in North-west Mexico', *Crop Science*, 37, pp. 36-42.

Sen, A. (1981): *Poverty and Famines. An Essay on Entitlement and Deprivation* (Clarendon Press, Oxford).

PROSPECTS FOR INCREASES IN RICE PRODUCTION

TE-TZU CHANG

Rice is a unique member of the grass family, and originated in the swamps of the Gondwana supercontient more than 130 million years ago. Its early progenitors independently evolved and diversified in Africa and in Asia into the two cultigens, *Oryza glaberrima* Steud. and *O. sativa* L., respectively. The Asian cultigen, following wide dispersal and remarkable diversification, became a cosmopolitan cereal grown in diverse ecosystems in over more than one hundred countries of the world. It is the most preferred starchy food in the developing world and shares equal importance with wheat.

RICE IN THE ECONOMY OF THE DEVELOPING WORLD

In the mid 1990s, the world rice area amounted to nearly 150 million ha, of which more than 130 million ha are in Asia, about six million ha in South America, 1.7 million ha in North and Central America, and slightly over seven million ha in Africa. World rough rice (paddy) production reached 534 million Mt in 1994, of which 482 million Mt (>90 per cent) were harvested in Asia. Rice and wheat furnished about forty per cent of the coloric intake of the Asians. As a comparison, world wheat production in 1995 totaled 547 million Mt harvested from 219 million ha of land. Asians are the dominant consumers of rice (IRRI, 1995, 1997; FAO, 1996).

Much of the rice grain produced on Asian farms is locally milled and consumed by dwellers in towns and cities. Less than five per cent of the crop enters international trade. Thailand, Pakistan, Myanmar, India, Vietnam and China (counterbalanced by massive wheat imports) are the notable exporters. Most rice eaters in Africa, the Middle East and Latin America depend on imported rice. World rice price remained low from 1975 through 1990 (David, 1991; IRRI, 1995, 1997).

RICE-GROWING AGRO-ECOSYSTEMS

A remarkable feature of rice production is the diverse hydro-edaphic-cultural regimes under which rice cultivars have adapted, following ten millennia of dispersal, domestication, mutation-hybridization, acclimatization and selection, both natural and man-made (Chang, 1985b).

Following refinements in cultured practices, five agro-ecosystems may be categorized: (1) irrigated wetland, (2) rainfed wetland of shallow water depth, (3) flood-prone wetland, including the tidal swamps, (4) deep water rice, and (5) dryland rice. These are described in table 1. Rice is the only cereal that can thrive in standing water. Rice plants can also fix nitrogen from the air through soil microbes present in the root zone.

Whereas irrigated rice excels wheat and corn in yield, rice yields have been long depressed in areas where chronic water deficit (drought) or excess (flooding) prevails, or where soil productivity is low due to inherent low fertility or toxicity problems.

Table 1. *Five major agro-ecosystems of world rice production.*

Ecosystem	Standing water depth.	Planting method	Dominant variety group	Planted area (% of world total	Production (%) of world total	Average yield (Mt/ha)	Growi season
Irrigated wetland	field bunded, <30 cm	Direct seeding or transplanted	Improved	53 (30)[1]	73	3.0-5.0	Wet/d
Rainfed wetland	0-30 cm	Direct seeding or transplanted	Improved or traditional	26 (24)[1]	17	2.0-4.0	Wet
Flood-prone/ tidal swamps	Variable, >50 cm	Direct seeding	Traditional			2.5	Wet
Deep water	1-5 m	Direct seeding	Traditional	8 (9)[1]	6	1.0-1.5	Wet
Dryland	None to occasional flooding	Direct seeding	Traditional	13 (6)[1]	4	1.0-1.5	Wet

Source: Information collated from Barker and Herdt (1985), Chang (1985b), IRRI (1989, 1997), David (1991).
Note: All figures shown are rough estimates recomputed from David (1991) and IRRI (1997).

[1] Percent shown in parenthesis are proportions based on the S & SE Asia subtotal relative to the Asia's subtotal area in 1994 1995).

[2] Rice yields are higher in the sun-lit dry season than in the cloudy wet season.

While irrigated culture together with rainfed wetland culture in more favorable areas with sufficient rainfall and fertile soil have served as the principal contributors to commercial production, the irrigated regime involves more labor-intensive operations and higher production costs.

The "Green Revolution" in Rice (late 1960s through the 1970s)

Before 1970 the average rice yield in the tropical rice-producing regions of Asia remained below 2 Mt/ha. The dramatic rise in yield and production, beginning with the southern nations of Asia in the late 1960s, won the highly publicized term "Green Revolution" (GR) in both wheat and rice. India led the large-scale planting of the semidwarf, nitrogen-responsive and high yielding rice varieties (HYVs) with the introduction of short-statured Taichung Native 1 that carried the recessive *sd*-1 gene for short-and-stiff culms.

The same gene present in Taiwan's land race of short culmed cvs. was also used by the breeders of the International Rice Research Institute (IRRI) in developing the higher yielding IR8 and many other IR varieties. IR8 and sister lines produced 11-12 Mt/ha record yields.

IR8 soon replaced Taichung Native 1. Likewise, IR8 was succeeded by later releases from IRRI that are earlier in maturing, more resistant to insects and diseases, and slightly improved in grain quality. The *sd*-1 gene has been widely used by breeders in Asia, Latin America and the USA (Dalrymple, 1986; Chang and Li, 1991).

The shortened cycles of breeding, testing, extension and cultivar replacement continue up to this day all over the world. Recent estimates place the total number of improved cvs. released by different agencies, later grouped as the modern varieties (MVs), at above 400. This represents an unprecedented world-wide program of collaborative breeding with IRRI providing the germplasm, technology, exchange, and training of young rice researchers in various disciplines (IRRI, 1972, 1980, 1985; Brady, 1975).

In the mid 1960s, China also bred semidwarf rices of high yielding ability from its semidwarf mutants, also having the *sd*-1 locus. Their impact on increased production was confined to the southern provinces, however (IRRI, 1980).

Then, in the 1970s, Chinese breeders succeeded in using cytoplasmic male-sterility from a wild relative in developing higher yielding F_1 hybrids. The yield advantage ranged from 10-30 per cent (Chang and Li, 1991). Adoption of this breakthrough is largely confined to China, due to the high technological requisites of seed production and high seed cost.

The crucial role of the improved varieties must be emphasized. In the seed-fertilizer-water based technology underlying the GR, the HYVs, irrigation water and fertilizers each contributed one fourth to the production increase in eight Asian countries during 1965-80 (Herdt and Capule, 1983). Moreover, seed is not only the carrier of the heightened yield potential but also a vehicle readily transported across geo-political boundaries. As a consequence, public and private efforts in seed multiplication and distribution, followed by international and institutional exchange, received greatly increased attention and support.

Initial plantings of IR8 on irrigated farms under increased fertilization scored yield increases of over 30 percent. News of the hiked harvests, unheard of before, spread quickly and lent impetus to the rapid spread of seed and associated cultural improvements in the Philippines, Malaysia, Indonesia, Vietnam, Sri Lanka, India and Pakistan. Soon, the exciting information and improved seed went to Africa and Latin America. The HYVs scored impressive adoption in South America, especially in Colombia (Dalrymple, 1986).

The momentous developments continued though the 1970s. From the 9.6 million ha of planted area in tropical Asia, the HYV adoption rose to 35 million ha in 1981-82. Adding the planted areas in China, North Korea and other centrally planned economies, the MV area amounted to 73 million ha in the early 1990s (Chang, 1997), surpassing that of wheat. The enormous growth in MV area was accompanied and made possible by public and private investments: price support or subsidies or loans, expanded irrigation projects, fertilizer plants, processing and storage facilities, roads and transportation means. It was indeed a rural based revolution, and greatly benefited farmers, low-income consumers, and governments. Meanwhile, quickened human population growth was sustained by the increased food output (Chang, 1987).

THE POST-GR YEARS (EARLY 1980S TILL THE PRESENT)

The expansion in MV area and the accompanying growth in yield and production continued through the ensuing two decades, though the total rice area has stagnated and even shrunk, and the irrigation projects have slackened (Chang, 1988; David, 1991). In short, the growth rates of vital factors have decelerated (Hossain, 1996). A variety of politico-economic factors have interplayed in different rice producing countries, each in a peculiar manner (Chang, 1988; 1993; David, 1991; IRRI, 1997a). These changes have led to a complex and intriguing situation: (1) domestic prices remained low till 1991, (2) production continued to rise at an annual rate of 2.7-3.2 per cent in South and Southeast Asia, 3.0 per cent in Africa, and 2.4 per cent in Latin America during the 1980s, (3) yield grew 2.9 per cent in South Asia, 2.0 per cent in SE Asia, 1.7 per cent in Africa, and 2.8 per cent in Latin America (David, 1991). These growth rates are slightly higher than the population growth rate (c. 1.9 per cent), indicating an increased supply of rice *per capita*. The rates dropped after 1991, partly due to adverse weather conditions in some countries and spiraling production costs relative to domestic prices in most countries. The yield growth rate decreased from 2 per cent in 1980-90 to 1.1 per cent in the 1990s (USDA, 1997).

For instance, the ratio of nitrogen fertilizer cost to the added rice harvest in the 1970s was 10 kg of rice to 1 kg of fertilizer; in the late 1980s, the ratio dropped to 5:1 (David, 1988). It is a common trend that once self-sufficiency is attained, the local governments cut back on the support price/loan or subsidy, dampening the farmer's interest in further production increase.

As of 1993, the ratio of MV adoption was 40 per cent in Bangladesh, 70 per cent in India, 90 per cent and above in the Philippines and Sri Lanka, while Thailand remained under 15 per cent (David, 1991; IRRI, 1995). These figures follow the proportion of irrigated land in each country and appear nearly saturated after large irrigation projects tapered off in the 1980s.

Significant gaps exist between on-farm yield and experiment station yield (yield gap I), and much greater margins persist between on-farm and potential farm yield (gap II). The present actual farm yields range from 3 to 5 Mt/ha. Yield gap I varies from 0.5 Mt in unfavorable East India, to over 1 Mt in southern India and Thailand. Yield gap II (<2 Mt) between actual and potential farm yield is generally greater than yield gap I, indicating ample room for the farmers to upgrade their yields (Herdt, 1996).

Inspirer of the less than well planned moves during the early years of the GR, seed-water-fertilizer based technology has certainly provided enormous rice production increases in Asia: from 290 million Mt of rough rice in 1970 to 482 million Mt in 1995. The gains have enabled billions of people to enjoy this easy-to-prepare and tasty cereal and staved off serious food shortages from the early 1970s till 1997. Public supported investments and internationally oriented research have paid splendid dividends (Evenson and Flores, 1978; Hayami and Ruttan, 1985). The enormous returns from the combined efforts of researchers, extension workers and rice farmers are depicted in figure 1.

During 1998, climatic aberrations of unprecedented magnitude struck Asia's rice bowls and wiped out much of the past gains. Rice shortage surfaced in several important rice-producing countries. Reserves in most countries were reduced to an all-time low.

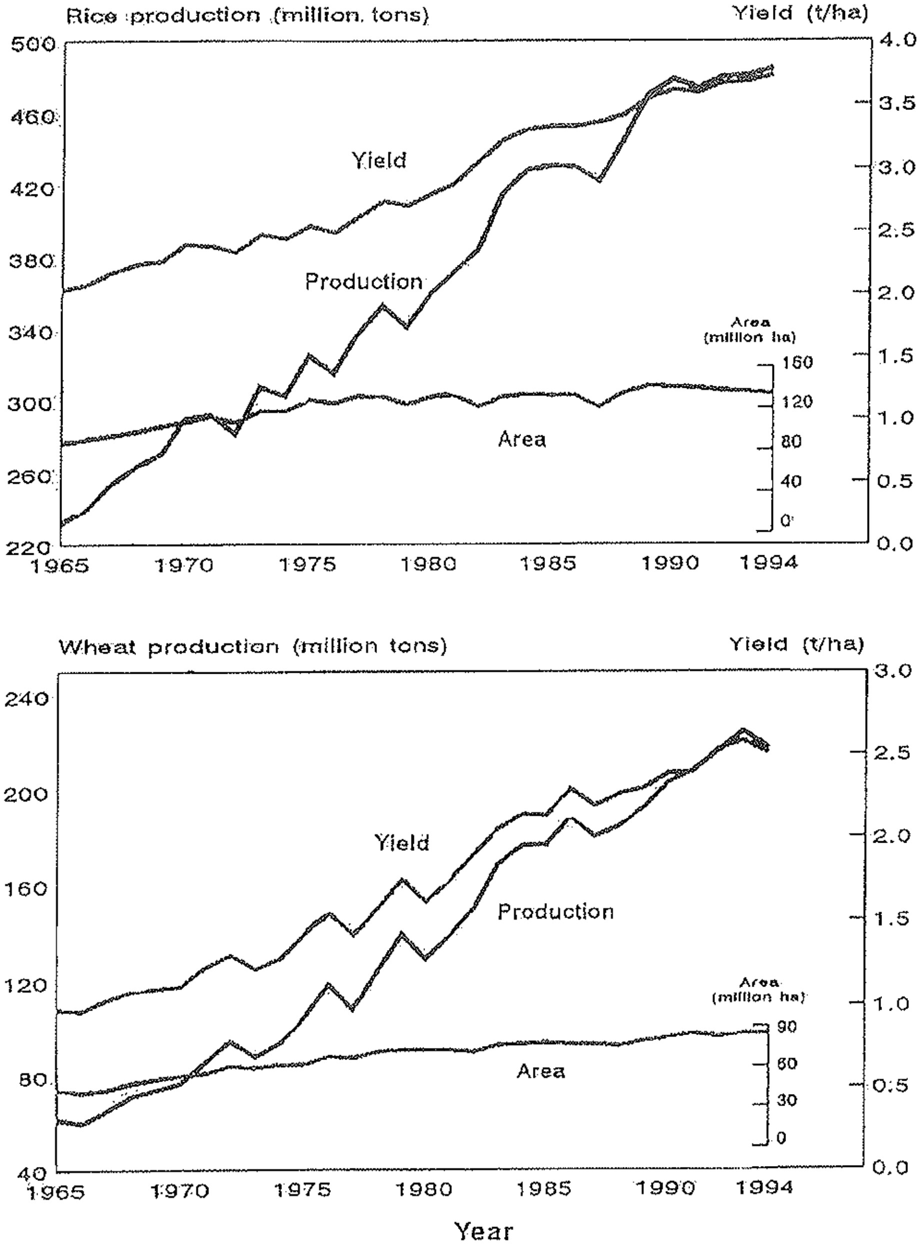


Fig. 1. Trends in Asian rice and wheat production, area and yield, 1965-1994. Prepared by Adelita Palacpac (formerly of IRRI), based on *Would Rice Statistics 1993-94* (IRRI, 1995) and the *FAO Agrostat Database* for the same years.

CONSTRAINTS ON SUSTAINED INCREASES IN RICE PRODUCTION

Can we maintain the momentum generated by the GR in the foreseeable future? My answer is simply: 'No'.

A growing number of challenges face rice researchers, growers, decision-makers, and consumers. The constraints are grouped and briefly discussed as follows. The broad issues and integrated factors were covered by IRRI in its 1988 research strategy review (IRRI, 1989).

1) *Land.* The supply of new land for growing rice is limited to yet undeveloped areas in the humid tropics now occupied by forests (standing or denuded) and tidal swamps. Land development will be prohibitive in cost and detrimental to environmental protection. Meanwhile, existing rice land of good productivity is continually lost to urban growth and other development projects. Transmigration attempts have yielded poor results.

2) *Water.* Due to past failure to conserve and efficiently use water, this precious resource has emphasised its limited supply because of increasing demands by industry and expanding population centers. Moreover, rice culture is wasteful in water use and therefore loses economic competitiveness. A prevalent failure to protect the watersheds is leading to costly rehabilitation or the abandonment of existing hydraulic facilities. New irrigation projects are few and more costly. Water quality has emerged as a constraint in irrigated rice areas where saline water was used. Rising salinity and an accompanying zinc deficiency are the result of drawing excess underground water for irrigation.

3) *Soil productivity.* The carrying capacity of rice soils has been on the decline (Flinn and de Datta, 1984) following the continuous monoculture of rice, the exclusive use of chemical fertilizers, mainly consisting of nitrogen, and little addition of organic manures.

4) *Yield plateau.* Top yields of 11-12 Mt/ha were established by IR8 and sister lines in the late 1960s (Chang and Li, 1991). Though some of the earlier maturing lines produce more rice per day in the field, no new record of yield per ha per crop has been reported. The average wet season yield on irrigated farms stayed below 4 Mt/ha. It is imperative to raise the potential yield through a variety of approaches: genetic, physiological or a combination of both. Genetic engineering may help to transfer the heterotic mechanism into purelines or to incorporate certain C4 pathway components into the C3 rice plant. A 15 Mt top yield is deemed feasible by some crop physiologists (cf. Chang, 1988).

5) *Yield stability.* In addition to highly variable weather, tropical rice production has been destabilized by recurrent epidemics of insects and diseases, several of which were new arrivals after the HYVs were grown in multiple cropping and under intensive practices. The HYVs have a common lineage, the same *sd*-1 locus, and often the same cytoplasm. The heavy use of nitrogen fertilizer and dense planting are liable to have a predisposing effect on host plant reaction. Staggered plantings and wide use of the same "resistant" cv. have intensified the epidemics (Chang, 1993). It is imperative to reinstate genetic diversity in the major cvs, broaden and diversify the resistance sources, and rotate the cvs. in successive crops. In addition, vigorous weed growth in the tropics continues to depress crop yield.

Abiotic stresses, such as extreme temperatures, water deficit or flooding or both in alternation, increasing pollutants, and soil problems persist and affect stable harvests. Varietal improvement offers one avenue for the rice plant to tolerate these stresses.

6) *Farmer's practices.* There is much room for rice farmers in the tropics to receive and practice the right technology in soil and water management, the use of agro-chemicals, the choice of improved cvs. in successive rice cropping areas, and the organisation of community-wide efforts. The efficiency of nitrogen fertilizer has remained low at 40 per cent. Improper use of insecticides has led to a resurgence of the brown planthopper. Misuse of improved cvs. has resulted in quick breakdowns of the new resistant cvs. (cf. Chang, 1988, 1993; Fox, 1993). Later developments in Indonesia have shown the benefits of integrated pest management and community efforts. Cost-cutting farm machinery of local manufacture will reduce labor costs and the increasing dependence on women and children in labor-intensive operations.

The yield gaps must be narrowed. With the help of researchers, advice from extension staff and government assistance in certain areas, such efforts will strengthen the rice farmer's ability to compete in crop production while the demand for rice continues to grow.

7) *Equitable returns for rice farming.* Since 1983, the declining domestic price of rice in real terms has prevailed in tropical Asia (see David, 1991) while production costs have continued to rise (Yap, 1991; Hossain, 1996). The picture has slightly improved since 1991. The rice shortages of 1998-99 will enhance prices. However, after years of neglect and public apathy, plus the migration of able bodied youth to urban areas, rice farmers no longer show the enthusiasm of the 1970s in upgrading rice yield (a personal observation). The sad fact is that the human factor is an irreversible trend.

At a 1991 international meeting on the environmental future of Southeast Asia – the area of greatest potential promise – the alarming depletion and limited capacity of natural and biological resources for future exploitation formed the basis of a consensus (see Brookfield, 1993). We need more in-depth studies like the above work and the present study-week on food needs. It is imperative to inform all sectors of society about impending needs.

It is sad that rice farmers have not received their share of the increased output from urban consumers after the long years of depressed domestic rice prices. Yet, the rice farmers strove to sustain production increases during the 1980s (David, 1991).

THE IMPENDING CHALLENGES OF THE COMING DECADE

All studies by agencies concerned with world food and agriculture – FAO, USDA, the World Bank, the international agricultural research centers (IARCs), IFPRI, and others – have projected an increasing demand for rice over and much above the 1997 level by rice-dependent nations of the developing world. These are based on projected population increases and changes in *per capita* intake. The actual demand will depend on the affordability of rice to the low-income masses, however.

A crucial question that follows is: who will carry out the essential activities to meet this daunting challenge? Rice farmers, the rice research community, governments and urban consumers, all have a vital part to play. Among these groups, the rice research community is again destined to spearhead the mission and to a greater extent than before.

Within the research sector, the varietal improvement group will again play a leading role, basing itself on past experience and true need.

But it also requires more vigorous and better-coordinated inputs from associated disciplines: physiology, agronomy, the soil and water sciences, pathology, entomology, biochemistry, agricultural engineering, climatology, and the social sciences. National research priorities and their research teams in various research institutions also need to be re-examined, reorganized and improved. In short, an all-out thrust is imperative in order to attain greater efficiency and speed than has been achieved so far.

Some of the planning and field testing also requires inputs from experienced farmers. So far, farmers have played a passive role in developing improved field practices.

How can we achieve further advances in varietal improvement? Past experience has amply shown that exploiting the required genetic potentials in the obscure germplasm and the wild relatives offers the only viable pathway to meet the desired objectives. With the markedly expanded genepools, assembled by IRRI and cooperating national centers during 1973-85, and over 80,000 accessions strong, we will beable to provide the missing components for the cvs. of the future. Innovations from biotech will assist a speedier transfer and incorporation of novel gene-complexes. Associated disciplines are also in a better position to achieve the new advances in overcoming abiotic stresses.

On the other hand, the increasing emphasis on biotech since the mid 1980s has led to fierce competition between the conventional types of research, the "bread-and-butter" sector, and the biotech workers, resulting in a severe curtailment of the former group and, more tragically, a move of numerous young scientists to join the latter's ranks. The inbalance in human and financial resources allocation is drawing off vital support from the research sector of mission-oriented workers who have sustained conventional research in the past and who are indispensable to attaining goals in the future. The more youthful research managers and staff have over-zealously followed the biotech craze without realizing that the long path from identifying the desired genetic source to its actual use involves a series of steps and several related disciplines in order for the product to reach the farms. The protracted process is shown in figure 2 where the genetic engineering process with exotic germplasm is just the beginning of the germplasm enhancement process or prebreeding phase, and takes place before actual breeding operations begin (see Chang, 1985a). Meanwhile, coordinated inputs of the "bread-and-butter" kind will ensure the breeder's output is a viable one.

In the history of rice improvement, the multidisciplinary Genetic Evaluation and Utilization (GEU) Program instituted by IRRI in the mid 1970s, together with national efforts of a similar approach, were instrumental in sustaining the earlier advances of the GR. Genes taken from obscure or wild germplasm have furnished the source for both biotic and abiotic tolerances. A training component and an international network of collaborative testing were associated products of the approach. The world-wide program greatly enhanced national capabilities in rice research and improvement (Brady, 1975; IRRI, 1985). The GEU approach was later adopted by other international research centers of various food crops. Unfortunately, severe fund and personnel cutbacks in the past decade at all centers have stymied these projects. The research personnel has not been replenished to date. In a time of crisis like this, it would be extremely difficult to re-assemble the research teams. The tragic downsizing of all the IARCs has adversely affected agricultural research progress on the food production front.

Moreover, future challenges will call for vigorous efforts to upgrade

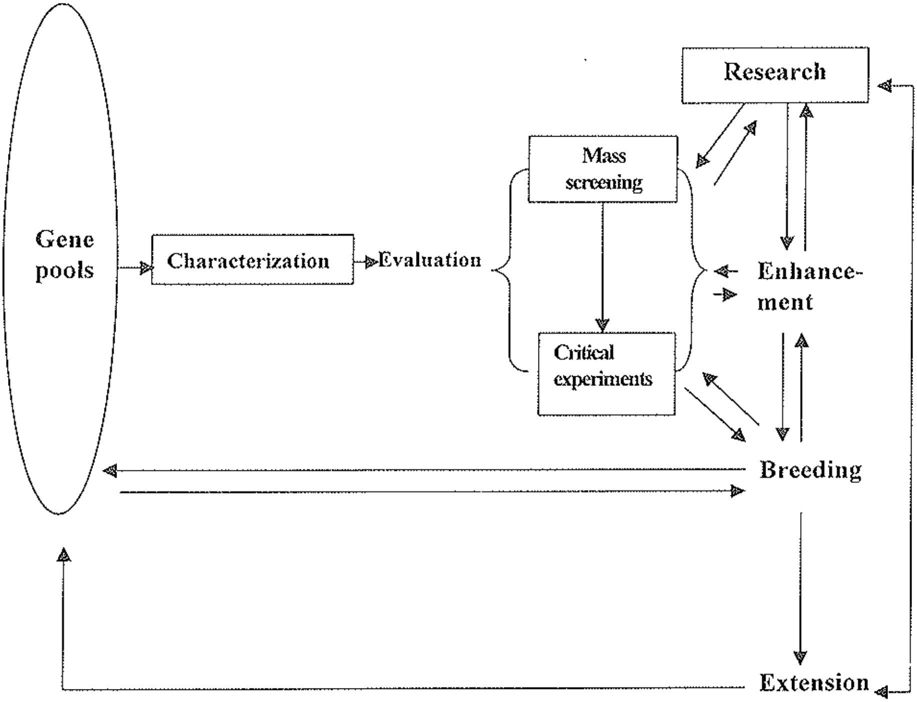


Fig. 2. The crucial role of germplasm evaluation-research-enhancement in crop improvement.

crop productivity with diminishing resources. More sustainable measures should be taken based on existing technology to cut production costs and to conserve limited resources (see Chang, 1998a). Increased inputs from agronomists, soil scientists, crop physiologists, plant protectionists, agricultural engineers, agricultural economists, and extension personnel, together with the participation of famers in applied research, are sorely needed to attain progress in this challenging task and to make up for lost time.

One crucial area requiring close inter-disciplinary collaboration is the upgrading of the efficiency of water and fertilizer use. Agronomic testing can be carried out early in the breeding process and in farmers' fields.

Rice workers also need to direct public attention to the impending needs of the research sector: their concern and action will determine the future supply of rice. Thus far, the labor-intensive and painstaking task of growing rice has been little respected and supported. I can recall that during the late 1960s the food crisis led the public and decision-makers, and their spouses as well, to talk about rice and wheat flour on a daily basis.

As in the early days of the GR, hard-pressed governments need to appoint non-agricultural but dynamic ministers to take charge. A crisis calls for unusual measures. During that period, I was also bemused by the sudden change in title among rice researchers of an important rice-growing nation from "Botanists" to "Breeders". Therefore, I have faith in the human capacity to respond to a major crisis.

The bottleneck in rice improvement apparently lies in the stagnant yield potential. At the 1988 IRRI strategic review, a plan was drawn up to concentrate research efforts on a more physiologically efficient plant type under direct seeding in irrigated rice that would produce a higher harvest index and earlier maturity under heavy fertilization. It was termed the "Improved Plant Type", or, in recent misquoted news reports, "Super Rice". The new breeding objective was more easily drawn up on paper than obtainable in the field. Since then, after hundreds of crosses were made to incorporate heavy-bearing panicles from the javanica race, poor grain setting actually lowered the yield (Khush, 1996; IRRI, 1997b), probably because of complex gene interactions that affect starch accumulation during grain development (Ishii, 1998; see also L.T. Evans, in these proceedings). The interracial partial sterility in rice has been a long recognized phenomenon (see IRRI, 1964). Other approaches such as using cultivated x wild derivatives, the apomictic route, and wide interracial crosses (see Khush, 1998), face the same need to upgrade the agronomic worth of the new genetic lines by the germplasm enhancement process; namely, a time frame of at least 5-10 years.

What can we draw from the 15-year intensive activities in rice biotech? The efforts with regard to gene mapping and tagging have made impressive advances, but in a way largely unrelated to agronomic traits. A long list of selected economic traits amenable through biotech manipulation (Herdt, 1991) indicates that only a small number of major genes control these traits and that conventional hybridization can also effectively attain the limited objective. In other words, the path to obtaining engineered products remains a long and tortuous one.

Moreover, direct seeding in the tropics requires thorough land preparation, precise water control, effective weed control, and improved machinery. Rice farmers on small farms are yet to be prepared for such high technology.

Turning to the unfavorable agro-ecosystems that have experienced long depressed yields and have been neglected by national agencies, investments for future improvement would be costly in relation to the returns. They will probably remain at the subsistence level. Retention of deepwater rice and tidal swamps are also important to environmental protection.

Outlook for the Early Twenty-first Century – A Personal View

As was pointed out by a community of concerned scientists (IRRI, 1989), the prospect for increased rice production after the year 2000 will hinge on the potential increase from the irrigated (complete or partial) fields and the favorable rainfed-wetland sector. Raising the yield potential, safeguarding the advances of past research, improving the diffusion of improved technology, and reducing the yield gaps are the focal points for future endeavor.

From the present standpoint, how much can we visualize for the next five to ten years?

As a crop scientist, I shall confine myself to production-related technological aspects that will fuel production increase in the more favorable rice producing environments.

1) *The favorable forces.* Compared to the early GR years, rice research will benefit from a richer and broader germplasm pool, recent advances in research technology, more trained workers, and more experienced farmers. The looming rice crisis in the tropics will spur increased support from public sources. Rice prices are certain to rise and encourage renewed interest on the part of the growers. These form the background to renewed research thrusts.

2) *Constraints on research advances.* A recurrence of the nearly magical effect of the *sd*-1 gene is not in sight. No dramatic breakthroughs in technology is within easy reach. Advances will largely depend on the slow and painstaking process of assembling and integrating various building blocks of research advances. Research management needs to be streamlined and the morale of mission-oriented researchers revived.

3) *Making up the recent losses.* During late 1997 and though 1998, disastrous weather abberrations associated with the El Niño phenomenon greatly affected rice production in many parts of Asia and in Brazil. Most severely affected in 1998 were the tropical countries in South and Southeast Asia and parts of central China. Prolonged drought in Indonesia forced it to import nearly six million tons of rice, a record figure for any country in a single year (Kotschwar and Childs, 1998). The Philippines, Bangladesh and Brazil also imported over one million tons each. The challenges involved in reviving the rice farmers' capacity to refill the empty granaries and enabling the governments to repay the costs of massive imports will place a heavy burden on the national economies of the region.

With diminishing and costlier resources, more sustainable measures need to be adopted or developed. More young workers should be trained in larger numbers and on the new research concepts based on team work. The international centers should be reinvigorated and supported on a more durable basis. A balance between intelligence property rights and accessibility of patented genes to public-supported breeding must be reached. Farmers should have a greater voice and role in research formulation as well as improved representation in government and legislative circles.

In the light of the lingering world-wide economic gloom and recent climatic calamities over much of the rice-producing region world, the agricultural sector will certainly suffer. A scarcer supply of rice and higher prices will force the landless tillers and low-income consumers to fall back on cheaper sources of food: wheat, maize, coarse cereals, root crops, beans, bananas and other starchy fruits, to supplement the caloric supply. Though large-scale famines and related civil strife may not appear in the immediate future, food shortages of longer duration will emerge, if the prevailing handicaps persist. And, as population growth continues unabated and at the going rate, food production will never be able to catch up with the anticipated demand. The scenario will be fearful. Therefore, we cannot expect food sufficiency until population growth is contained.

We need to act on both fronts and the time is now!

REFERENCES

Barker, R., and Herdt, R.W. (1985): *The Rice Economy of Asia* (Washington, D.C., Resources for The Future), p. 324.

Brady, N.C. (1975): 'Rice Responds to Science', in A.W.A. Brown (ed.), *Crop Productivity-Research Imperatives* (East Lansing, Midrigan Agricultural Experiment Station), pp. 62-96.

Brookfield, H. (1993): 'Conclusions and Recommendations', in H. Brookfield and Y. Byron (eds.), *South-East Asia's Environmental Future – The Search for Sustainability* (Tokyo, United Nations University Press), pp. 363-373.

Chang, T.T. (1985a): 'Germplasm Enhancement and Utilization', *Iowa State J. Research*, 59, pp. 399-424.

— (1985b): 'Crop History and Genetic Conservations: Rice – a Case Study', *Iowa State J. Research*, 59, pp. 425-455.

— (1987): 'The Impact of Rice on Human Civilization and Population', *Interdisciplinary Science Reviews*, 12, pp. 63-69.

— (1988): 'Sharing the Benefit of Bioproduction with the Developing World', *The New Biology – Its Challenges to Society* (Canberra, International Union of Biological Sciences), pp. 58.

— (1993): 'Sustaining and Expanding the "Green Revolution" in Rice', in H. Brookfield and Y. Byron (eds.), *South-East Asia's Environmental Future – The Search for Sustainability* (Tokyo, United Nations University Press), pp. 201-210.

— (1997): 'The Green Revolution: Achievements and Prospects' (in Chinese), *Scientific Agriculture* (Taipei), 45, pp. 88-98.

— (1998a): 'What Constitute Sustainable Agriculture?', in C.H. Chou and K.T. Shao (eds.), *Frontiers in Biology: The Challenges of Biodiversity, Biotechnology and Sustainable Agriculture* (Taipei, Academia Sinica), pp. 167-172.

— (1998b): 'What Can Crop Scientists Contribute to Meeting Future Food Needs in the Twenty-First Century?' in H.Y. Lu, J.M. Sung and C.H. Kao (eds.), *Asian Crop Science 1998* (Taichung, Chinese Society of Agronomy), pp. 11-24.

Chang, T.T., and Li, C.C. (1991): 'Genetics and Breeding', in B.S. Luh (ed.), *Rice* V. 1, *Production* (New York, AVI-Van Nostrand Reinhold), pp. 23-101.

Dalrymple, D.G. (1986): *Development and Spread of High-yielding Rice Varieties in Developing Countries* (Washington, D.C., U.S. Agency for International Development), p. 99.

David, C.C. (1988): *Why the Philippines Imported Rice in Recent Years?* (Los Baños, IRRI Agric. Economics Dept. Paper), p. 21.

— (1991): 'The World Rice Economy: Challenges Ahead', in G.S. Khush and G.H. Toenniessen (eds.), *Rice Biotechnology* (Oxon, C.A.B. International and I.R.R.I.), pp. 1-18.

Evans, L.T. (1999): 'Physiological Limits to the Improvement of Crop Yield' (Vatican, Pontifical Academy of Sciences, 1999, Study Week on the Food Needs of the Development World in the Early 21st Century).

Evenson, R.E., and Flores, P.M. (1978): 'Social Returns to Rice Research', in *Economic Consequences of the New Rice Techology* (Los Baños, IRRI), pp. 243-265.

F.A.O. (Food And Agriculture Organization of the United Nations) (1996): *The Sixth World Food Survey* (Rome, Food and Agriculture Organization of the U.N.), p. 153.

Flinn, J.C., and de Data S.K. (1984): 'Trends in Irrigated Rice Yields Under Intensive Cropping at Philippine Research Stations', *Field Crops Research*, 9, pp. 1-15.

Fox, J.J. (1993): 'Ecological Policies for Sustaining High Production in Rice: Observations on Rice Intensification in Indonesia', in H. Brookfield and Y. Byron (eds.), *South-East Asia's Environmental Future: The Search for Sustainability* (Tokyo, United Nations University Press), pp. 211-223.

Hayami, Y., and Ruttan, V.W. (1985): *Agricultural Development: An International Perspective* (Baltimore, Johns Hopkins University Press), p. 506.

Herdt, R.W. (1991): 'Research Priorities for Rice Biotechnology', in G.S. Khush and G.H. Toenniessen (eds.), *Rice Biotechnology* (Oxon, C.A.B. International and I.R.R.I.), pp. 19-54.

— (1996): 'Summary, Conclusions and Implications', in R.E. Evenson, R.W. Herdt and M. Hossain (eds.), *Rice Research in Asia: Progress and Priorities* (Oxon, C.A.B. International and I.R.R.I.), pp. 393-405.

Herdt, R.W., and Capule, C. (1983): *Adoption, Spread and Production Impact of Modern Rice Varieties in Asia* (Los Baños, International Rice Research Institute), p. 54.

Hossain, M. (1996), 'Recent Developments in the Asian Rice Economy: Challenges for Rice research', in R.E. Evenson, R.W. Herdt and M. Hossain (eds.), *Rice Research in Asia: Progress and Priorities* (Oxon, C.A.B. International and I.R.R.I.), pp. 17-33.

IRRI (1964): *Rice Genetics and Cytogenetics* (Amsterdam, Elsevier), p. 274.

— (1972): *Rice Breeding* (Los Baños, International Rice Research Institute), p. 728.

— (1980): *Rice Improvement in China and Other Asian Countries* (Los Baños, I.R.R.I.), p. 307.

— (1982): *Rice Research Strategies for the Future* (Los Baños, I.R.R.I.), p. 553.

— (1985): *International Rice Research: 25 Years of Partnership* (Los Baños, I.R.R.I.), p. 188.

— (1989): *IRRI Toward 2000 and Beyond* (Los Baños, I.R.R.I.), p. 66.

— (1995): *World Rice Statistics, 1993-94* (Manila, I.R.R.I.), p. 260.

— (1997a): *Rice Almanac,* second edition (Los Baños, I.R.R.I., C.I.A.T. and W.A.R.D.A.), p. 181.

— (1997b): *Program Report for 1996* (Los Baños, I.R.R.I.), p. 176.

Ishii, R. (1998): 'Message from a Crop Physiologist to the Crop Breeders on Higher Yields of Rice Under LISA Conditions', in H.Y. Lu, J.M. Sung and C.H. Kao (eds.), *Asian Crop Science 1998* (Taichung, Chinese Society of Agronomy), pp. 1-10.

Khush, G.S. (1996): 'Prospects of and Approaches to Increasing the Genetic Yield Potential of Rice', in R.E. Evenson, R.W. Herdt and M. Hossain (eds.), *Rice Research in Asia: Progress and Priorities* (Oxon, C.A.B. International and I.R.R.I.), pp. 59-71.

— (1998): 'Innovative Approaches for Improving the Yield and Grain Quality of Rice, in H.Y. Lu, J.M. Sung and C.H. Kao (eds.), *Asian Crop Science 1998* (Taichung, Chinese Society of Agronomy), pp. 436-450.

Kotschwar, L., and Childs, N.W. (1998): 'El Niño Drives Record World Rice Trade in 1998', *Economic Research Service / USDA* 1998 (September), pp. 26-31.

USDA (1997): *Production, Supply and Distribution Database* (Washington, D.C., U.S. Department of Agriculture).

Yap, C.L. (1991): *A Comparison of the Cost of Producing Rice in Selected Countries,* FAO Economic and Social Development Paper No. 101 (Rome, FAO).

REALIZING YIELD GAINS FOR FOOD STAPLES IN DEVELOPING COUNTRIES IN THE EARLY TWENTY-FIRST CENTURY: PROSPECTS AND CHALLENGES

DEREK BYERLEE, PAUL HEISEY, and PRABHU PINGALI

INTRODUCTION

The past three decades have seen a remarkable transition in the developing world from growth in food production largely based on expansion of land area and irrigation infrastructure to one based on intensification through increased crop yields and multiple cropping. Yield growth has accounted for nearly 90% of increased cereal production in developing countries since the green revolution and average cereal yields in developing countries have more than doubled in thirty years – an unprecedented achievement in the history of world food production. This impressive growth has enabled *per capita* cereal production in developing countries to increase by a quarter at the same time that *per capita* cereal area declined by nearly one half.

In the coming decades, the challenge of crop yield intensification will be magnified as the absolute area sown to cereals is now *declining* in the two most populous countries, China and India, with increasing pressure for land from higher value crops and non-farm uses (table 1). While there are still extensive areas of land that could be brought under cultivation, most of these are marginal for food production or characterized by a fragile resource base, such as the tropical forests. With the exception of Sub-Saharan Africa, all developing regions will have to rely almost entirely on increased crop yields and higher cropping intensity for domestic supply of future food needs.

Best estimates are that cereal yields will have to increase by about one third by 2020, or a growth rate of about 1.2%, if a modest decline in real food prices is to be maintained (Rosegrant, Leach, and Gerpacio, 1998). At

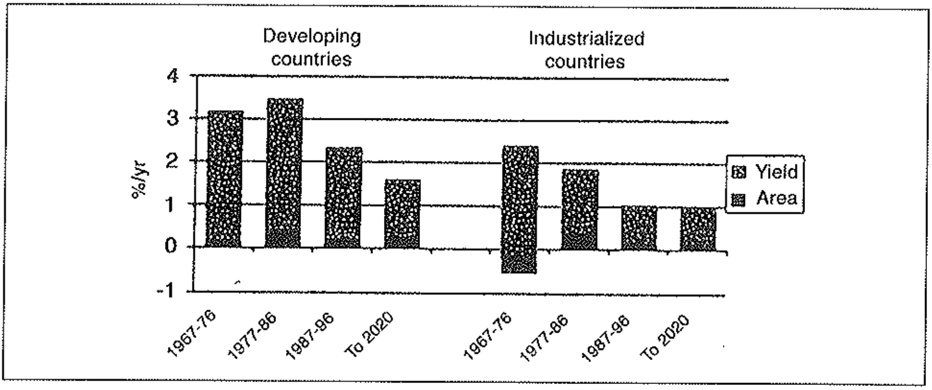
Table 1. *Growth rate (%/yr) of cereal area in developing and developed countries.*

Region / Country	1967-1976	1977-1986	1987-1996	1961-
China	0.92	–0.96	–0.03	–0.
India	0.41	0.07	–0.22	0.
South, East, & Southeast Asia, less China, India	0.74	0.99	0.80	0.
West Asia and North Africa	0.80	0.45	0.80	0.
Latin America	1.24	0.48	–0.49	0.
Sub-Saharan Africa	0.41	1.84	3.46	1.
All Developing Countries less China, India	0.75	1.06	0.87	0.
All Developing Countries	0.71	0.33	0.44	0.
All Developed Countries	0.64	0.29	–0.29	0.

first sight this does not seem to be a major challenge since it represents only half the rate of yield gains achieved over the past three decades (figure 1). However, as we show in this paper, several of the key sources of growth exploited in the recent past have been exhausted in many areas, and it is not immediately obvious how future yield gains will be achieved.

This paper briefly analyses changes in yields of food staples, sources of those changes, and the prospects for future yield growth. Since previous speakers will have examined yield potential, we focus on farm yields within the context of yield gap analysis. There are many ways of defining yield gaps, but we prefer that shown in figure 2 which distinguishes five levels; (i) theoretical maximum yields, (ii) best yields on experiment stations with all inputs optimized, (iii) average yields on experiment stations (e.g., in varietal trials), (iv) yields in researcher managed onfarm trials, (v) best farmer yields, and (vi) average farmer yields (Herdt, 1988). Our emphasis is on the yield gap on the right hand side of this spectrum, with a focus on economically exploitable yield gaps over the next two to three decades.

We also recognize at the outset a number of limitations to a yield focus. First, we must be conscious of the efficiency with which yield increases are obtained, recognizing the need for a continuing reduction in the cost of production if yield increases are to be translated into reduced real prices for poor consumers and if developing country farmers are to effectively compete in liberalized global food markets. Second, yield gains must be achieved in a sustainable manner that protects the natural resource base. Third, it is not sufficient to simply look at the proximate technological factors affecting



Source: FAOSTAT and Rosegrant *et al.*, 1998.

Fig. 1. Growth rate of area and yield of cereals by decade.

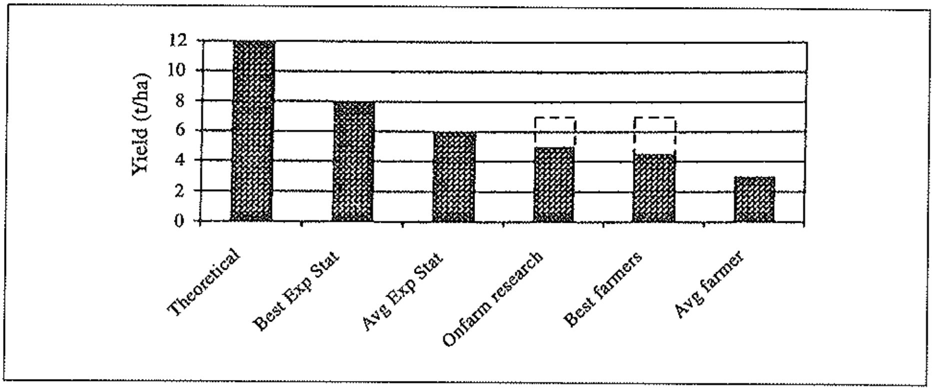


Fig. 2. Types of yield gaps.

yields. The development of technologies and farmers' decisions about their use are determined by the institutional and policy environment in which they operate. Hence the final section of this paper will address some key policy issues that will determine the realization of future yield gains. Fourth, at the global level, there is only a weak relationship between crop yields and the nutritional status of the population. In this paper, we focus on two regions where the great majority of the world's poor are located – South Asia and Sub-Saharan Africa: regions where increased food crop yields are essential to improve the food security of farm households and to stimulate broad-based economic growth and poverty alleviation. We also give considerable attention to crop yields in Asia as a whole, because of the high weight of Asia in world food production and consumption. Finally, we emphasize the major cereals, rice, wheat and maize, which constitute different percentages of calories consumed in the developing world. However, we also recognize the key role of secondary food staples – secondary cereals, especially important in marginal areas, pulses, a major source of protein, and roots and tubers, critical to food security in much of Africa.

RECENT YIELD TRENDS FOR FOOD STAPLES

The major cereals: is yield growth slowing?

Since 1961, cereal yields in developing countries have increased at an unprecedented rate of 2.5% annually. However, the evidence generally supports a slowdown in yields of food staples in the most recent decade, although this slowdown now seems less pronounced than we had anticipated in our earlier writings (Pingali, 1994; Morris and Byerlee, 1992). In addition, yields are slowing from the unusually high rate of growth in yields of rice and wheat stimulated by the green revolution in Asia. Overall, cereal yield growth in the past decade has been a historically respectable 2.0% per year.

To summarize the most important trends in recent yield performance by crop and region (tables 2-6):

Table 2. *Growth rates of yield* (%/yr) *for all cereals in developing and devel countries.*

Region / Country	1967-1976	1977-1986	1987-1996	1961-
China	3.28	5.08	2.32	3.7
India	1.93	2.58	3.05	2.6
South, East, & Southeast Asia, less China, India	2.32	3.08	1.50	2.0
West Asia and North Africa	1.78	1.91	1.98	1.8
Latin America	2.09	2.68	2.62	2.0
Sub-Saharan Africa	1.78	–0.20	–0.12	0.8
All developing countries less China, India	2.01	2.12	1.44	1.7
Developing countries	2.46	3.06	1.98	2.5
Developed countries	1.35	1.81	2.05	1.8
World	2.07	2.43	1.40	2.1

— Growth in rice yields in the last decade has slowed to 1.4% annually, half of the previous decade. Rice yields in East Asia now average over 6.0 t/ha (tables 3 and 4).

— Wheat yields have increased more rapidly than any other food staple with average growth rates of 3-5% in Asia, more than double yields in industrialized countries. The gap in wheat yields between industrialized and developing countries (a ratio of 2:1 in the early 1960s) has now been reduced to 1.2:1 (table 4). Growth in wheat yields has slowed in the past decade but is still a respectable 2.1% in developing countries (table 3).

— The recent slow down in yield growth in rice and wheat is consistent over regions, including industrialized countries (table 3).

— The performance of maize yields is highly variable across regions with no evidence of a slow-down. The high yield growth (and high absolute yields) in China contrast with low yields and a relative stagnation of yields in Sub-Saharan Africa where rapid increases in maize production have been achieved through area expansion. The yield gap between industrialized and developing countries also remains high for maize (table 3).

— For all three major cereals, yield growth in developing countries has exceeded that in industrialized countries over the past 30 years, a major switch from the pre-green revolution situation (table 3).

— There is increasing evidence that the growth in cereal yields in the most advanced areas has leveled off in Asia. When countries are stratified by cropping intensities, the rate of deceleration in yield growth is found to be higher for countries with higher cropping intensities where the land frontier has been exhausted, such as China, Korea, and the Philippines (Pingali, *et al.*, 1997).

Other food staples: few success stories to date

In contrast to the major cereals, yields of most other food staples have stagnated often at low levels in developing countries (tables 5 and 6). For example, there was almost no yield growth for secondary cereals (mainly sorghum, millet and barley) from 1977-96, outside India and China, and yields still average around 1 t/ha, about one quarter of yields in industrialized countries. Likewise, yields of food legumes increased at only 0.3% *per annum* from 1961 to 1996. Meanwhile food legume yields have increased rapidly in industrialized countries and there is a wide and growing gap with yields in developing countries – developing country yields now average only about one third of yields in industrialized countries. Finally yields of roots and tubers have also increased slowly at less than 1% annually, and virtually

Table 3. *Growth rates of yield* (%/yr) *for major cereals in developing and deve countries, 1961-96.*

Region / Country	1967-1976	1977-1986	1987-1996	1961-
Rice				
Southeast Asia	2.49	3.79	1.73	2.
South Asia	0.87	2.35	1.94	2.
China	1.44	4.41	1.42	2.
India	0.84	2.27	2.17	2.
Developing countries	1.61	3.14	1.40	2.
Developed countries	0.26	1.17	0.40	0.
World	1.41	2.99	1.41	2.
Wheat				
China	5.43	7.75	2.59	5.
India	3.48	4.05	2.85	3.
South, East, & Southeast Asia, less China, India	4.34	2.77	2.07	2.
West Asia and North Africa	2.51	2.28	1.42	2.
Latin America	2.06	4.93	1.37	1.
Sub-Saharan Africa	2.39	1.03	1.69	2.
All developing countries less China, India	2.68	3.09	1.35	2.
Developing countries	3.70	5.05	2.10	3.
Developed countries	1.87	2.48	1.71	1.
World	2.50	3.12	0.98	2.
Maize				
South, East, & Southeast Asia, less China	1.30	3.15	2.13	1.
China	3.97	4.39	3.20	4.
West Asia and North Africa	2.30	3.78	1.81	2.
Latin America less Brazil, Argentina, Chile	1.22	2.65	3.18	2.
Sub-Saharan Africa less South Africa	2.05	0.41	0.43	1.
All developing countries less China, Brazil, Argentina, Chile and South Africa	1.56	2.16	1.73	1.
Developing countries	2.51	2.68	2.76	2.
Developed countries	0.97	1.98	1.90	2.
World	2.25	1.91	2.16	2.

Table 4. *Average yield for major cereals in developing and developed countries* (ton/ha).

Region / Country	1961-1965	1992-1996
Rice		
Total Asia	1.9	3.7
Southeast Asia	1.7	3.3
South Asia	1.5	2.8
China	2.6	5.9
India	1.5	2.8
Developing countries	1.9	3.6
Developed countries	4.9	6.3
World	2.0	3.7
Wheat		
South, East, & Southeast Asia, less China, India	0.9	1.9
China	0.8	3.5
India	0.8	2.4
West Asia and North Africa	0.9	1.8
Latin America	1.4	2.3
Sub-Saharan Africa	0.8	1.6
Developing countries	0.9	2.5
Developing countries less China, India	1.0	1.9
Developed countries	1.8	3.1
World	1.2	2.5
Maize		
China	1.4	4.9
South, East, & Southeast Asia, less China	1.1	1.9
West Asia and North Africa	1.7	3.8
Latin America less Brazil, Argentina, Chile	1.0	2.1
Brazil	1.3	2.4
Argentina	1.8	4.3
Sub-Saharan Africa less South Africa	0.7	1.0
South Africa	1.2	2.0
All developing countries less China, Brazil, Argentina, Chile and South Africa	1.0	1.8
Developing countries	1.2	2.7
Developed countries	3.6	7.1
World	2.0	3.9

Table 5. *Growth rate* (%/yr) *for other cereals, roots and tubers and pulses in develo and developed countries, 1961-96.*

Region / Country	1967-1976	1977-1986	1987-1996	1961-
Sorghum, millet, barley and minor cereals				
China	2.89	2.38	3.65	2.9
India	2.06	–0.72	2.63	1.7
South, East, & Southeast Asia, less China, India	1.49	–0.17	–1.30	–0.1
West Asia and North Africa	0.75	1.51	2.20	1.0
Latin America	4.97	1.35	0.39	2.2
Sub-Saharan Africa	1.12	0.87	0.06	0.4
Developing countries	2.18	0.63	0.96	1.2
All developing countries less China, India	2.15	0.82	–0.27	0.8
Developed countries	0.58	1.51	1.04	1.3
World	1.69	1.25	–0.06	1.2
Roots and tubers				
China	6.96	1.85	1.79	2.3
India	3.20	1.66	1.33	2.3
South, East, & Southeast Asia, less China, India	1.79	1.25	–0.49	1.2
West Asia and North Africa	1.07	2.89	1.89	1.9
Latin America	–1.03	0.73	0.70	0.2
Sub-Saharan Africa	0.03	0.43	1.46	0.9
All developing countries less China, India	0.06	0.65	0.44	0.7
Developing countries	2.68	0.75	0.82	1.3
Developed countries	0.03	1.69	1.94	1.5
World	1.06	1.38	1.05	1.0
Pulses				
China	3.54	1.15	1.45	1.4
India	0.52	1.37	1.10	0.6
South, East, & Southeast Asia, less China, India	0.97	2.40	0.30	0.8
West Asia and North Africa	0.65	0.79	–0.05	0.0
Latin America	–1.13	–0.62	3.42	0.0
Sub-Saharan Africa	2.45	–1.27	–1.02	0.4
All developing countries less China, India	0.97	0.31	0.37	0.3
Developing countries	0.94	0.56	0.41	0.3
Developed countries	0.73	4.49	–0.29	2.6
World	0.79	1.37	–0.12	0.8

Table 6. *Average yields for all cereals, roots and tubers and pulses in developing and developed countries* (ton/ha).

Region / Country	1961-1965	1992-1996
All cereals		
China	1.5	4.6
India	0.9	2.1
South, East, & Southeast Asia, less China, India	1.6	2.9
West Asia and North Africa	1.1	1.9
Latin America	1.3	2.5
Sub-Saharan Africa	0.8	1.0
All developing countries less China, India	1.2	2.0
Developing countries	1.2	2.6
Developed countries	2.4	4.4
World	1.4	2.8
Roots and Tubers		
China	7.9	16.8
India	7.8	16.6
South, East, & Southeast Asia, less China, India	7.8	10.8
West Asia and North Africa	11.0	19.2
Latin America	10.2	11.5
Sub-Saharan Africa	5.8	7.8
All developing countries less China, India	7.3	9.3
Developing countries	7.6	11.5
Developed countries	18.7	31.7
World	8.7	12.7
Pulses		
China	1.0	1.4
India	0.5	0.6
South, East, & Southeast Asia, less China, India	0.6	0.7
West Asia and North Africa	0.9	0.9
Latin America	0.6	0.7
Sub-Saharan Africa	0.5	0.5
All developing countries less China, India	0.6	0.6
Developing countries	0.6	0.6
Developed countries	0.9	1.9
World	0.6	0.8

all of this has been through yield growth of potatoes in irrigated market-driven production in Asia.

These trends generally hold for all regions, including Asia, in part because secondary cereals and legumes have been increasingly displaced toward more marginal areas by the spread of irrigation and green revolution technology (i.e., wheat replacing cool season pulses in northern India, and maize replacing sorghum in the semi-arid tropics of Africa). The overall result has been *declining per capita* production and consumption of secondary foods, and in the cases of food legumes, sharply *rising* real prices over the long term. These trends directly contrast with the overall trends in major cereals.

SOURCES OF RECENT YIELD GROWTH AND THE CHALLENGE AHEAD

Since the 1960s when food crop yields were stagnating and many countries in Asia faced a food crisis, agricultural policy has focused on a strategy of increasing yields of major cereals through a package of practices designed to allow the substitution of scientific knowledge and external inputs for increasingly scarce land (Ruttan, 1998). This approach has been dominated by three factors; (i) the spread of modern input-responsive varieties as the lead technology, (ii) rapid increases in external inputs, especially agro-chemicals, and in Asia (iii), improved water supplies through irrigation. Public policy has been explicitly oriented to supporting this paradigm through investment in research, irrigation and market infrastructure, and subsidies on inputs, especially water and fertilizer.

The adoption of this package and the resulting yield growth can be divided into three distinct phases in areas characterized by land scarcity (Byerlee and Lopez-Pereira, 1994; Morris and Byerlee, 1998).

(1) *A "green revolution" phase* during which a technological breakthrough in the form of input-responsive modern varieties (MVs) provided the potential for a dramatic increase in land productivity. In this phase, first generation MVs were widely adopted along with modest levels of external inputs.

(2) An *input intensification phase* during which farmers rapidly intensified the use of purchased inputs (e.g., fertilizer) and capital (e.g., tube wells, machinery), resulting in movement toward the economically optimal use of these inputs.

(3) An *input efficiency phase* beginning after input use has reached high levels, during which farmers use improved information and management skills to substitute for higher input use, leading to more efficient uti-

lization of inputs while contributing to the sustainability of the resource base. At the same time, genetic yield gains are maintained through the regular adoption of newer generations of MVs.

An examination of sources of growth of yields in the recent past, confirms that these phase of yield growth hold over wide areas in the developing world.

Modern varieties as the lead technology

The major cereals: genetic gains through scientific plant breeding have been central to technical progress in yields for most of this century. Most studies suggest that about half of all yield gains can be attributed to genetic gains (summarized in Byerlee, 1994). In developing countries, the adoption of modern varieties (MVs) of cereals that began in the 1960s has progressed steadily over the past three decades. Currently about 60-70% of the combined rice, wheat, and maize area in developing countries is planted to MVs (table 7).[1] While the popular perception is that the green revolution was a rice and wheat revolution in irrigated areas, over the past 10-15 years most of the expansion in area under MVs has occurred in rainfed areas, beginning first with wetter areas and proceeding gradually to more marginal areas. Significantly, maize (all rainfed) has been a major success story in the diffusion of MVs in sub-Saharan Africa, where rice and wheat are less important food staples (Byerlee and Heisey 1993).

The remaining areas in the developing world where MVs are not widely grown possess one or more of the following characteristics (Byerlee, 1995):

— *Areas generally classified as marginal for crop production.* Although there have been some notable successes in developing MVs capable of tolerating soil stresses (e.g., for acid soils), MVs have not been adopted widely in areas where drought stress is frequent, or, in the case of rice, in areas where water control is very poor.

— *Areas with very poor infrastructure and limited access to markets.* These problems commonly affect maize and minor food staples, especially in the relatively land-extensive systems of Africa.

— *Areas where quality traits and by-products of local varieties outweigh the yield advantages of MVs.* This was common for some areas of high quality rice in Asia and for maize in Southern Africa, and many marginal areas, but is steadily being addressed by plant breeders.

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[1] Nowhere is this coverage more impressive than in spring bread wheats (the dominant wheat type in developing countries), where MVs now account for an estimated 93% of production in developing countries (Byerlee and Traxler, 1995).

Table 7. *Per cent area planted to modern varieties of rice, wheat, and maize in developing countries, 1970-90.*

	Rice			Wheat				Maize
	1970	1983	1991	1970	1977	1983	1990	1990
Sub-Saharan Africa	4	15	na	5	22	32	52	43
West Asia/North Africa	0	11	na	5	18	31	42	53
Asia (excluding China)	12	48	67	42	69	79	88	45
China	77	95	100	na	na	na	70	90
Latin America	4	28	58	11	24	68	82	46
All developing countries	30	59	74	20	41	59	70	57

Source: Byerlee, 1995.

In the post-green revolution era, adoption of successive generations of modern varieties now account for most genetic gains (as opposed to first time adoption of modern varieties). Over the long term, breeders have been able to maintain remarkable continuity in yield gains for major cereals. In the US, for example, since the diffusion of the first generation of hybrid maize varieties 70 years ago, newer higher-yielding hybrids have been released almost annually to provide a linear increase in yields *in farmers' fields* of about 50 kg/ha – or an average of 1.2% annually (Duvick, 1992). Likewise, genetic yield gains of 0.5-1.5% annually over a 30 year period have been well documented for developing country wheat varieties (Byerlee and Traxler, 1995). In rice, yield gains have been minimal but when expressed in yields per day and increased cropping intensity, genetic gains in rice due to release of earlier maturing varieties have been equally impressive.

These gains in yield potential have been accompanied by huge advances in resistance to major diseases and insect pests in all food crops. Over the past three decades an increasing share of breeding resources has been devoted to host-plant resistance (the ability of varieties to withstand pest damage), and particularly the maintenance of resistance in the face of evolving pest populations. At the same time, in place of a few dominant varieties typical of the green revolution, thousands of varieties have been developed for a multitude of agro-ecologies, cropping systems, and quality needs.

While there is debate about the likelihood that these gains can be maintained, the evidence on long-run genetic gains coupled with the potential for biotechnology tend to support the prospects for continuous genetic gains (also discussed in other papers in this study-week). However, there is also reason for concern (Byerlee, 1995). First, gains achieved over the long term tend to be linear, so that the percentage rate of gain has indeed slowed. Second, the rate of increase in the cost of crop breeding programs has far exceeded the rate of genetic gain. For example, while genetic gains in yields in US maize have averaged a little over 1% annually, research costs for maize hybrid development have grown by 7% annually over the past 50 years. It is not clear if public and private investment in varietal improvement will be able to sustain these cost increases. Finally, breeders are continuously incorporating new traits, such as tolerance to low nitrogen and new diseases, into their programs, adding to the complexity of producing new varieties and the potential for tradeoffs with yield gains. However, new molecular techniques, such as molecular markers, hold out the prospects for "precision breeding" and the potential to reverse the upward trend in cost per unit of genetic gain.

Secondary cereals, roots and tubers, and legumes: no comparable global figures on varietal uptake exist for the other important food crops but overall the use of improved varieties of secondary cereals, food legumes and roots and tubers is quite low. However, in Asia MVs of sorghum and millet are widely grown, covering half of the dryland area planted to these crops in India, for example (Pray, Ribeiro and Mueller, 1991). Among legumes, improved varieties of soyabeans are widely used in all regions, in part because soyabean is often a new crop whose area has expanded rapidly with the introduction of improved varieties. Improved potato varieties are grown on about 90% of developing country potato area reflecting the favorable environment under which they are usually grown (T. Walker, pers. com.). In Africa there have been notable successes in the adoption of improved cassava, the dominant food crop in some areas. For example, an estimated 60 per cent of cassava area in Nigeria, the largest producer, is sown to improved varieties.

But overall, technical change in these secondary food crops has been small, as reflected in low and stagnating yields. The displacement toward marginal areas, the replacement of legume rotations with inorganic fertilizers, and a wide variety of policy biases in research and extension programs, provision of irrigation water, and marketing infrastructure, have adversely affected the uptake of technology in these crops. However, in the late 1980s and 1990s a number of promising success stories have begun to emerge, including sorghum in parts of West Africa, cassava and cowpeas in the same regions, and mungbeans and pigeon pea in Asia (see Byerlee and White, 1997).

Irrigation

Irrigated area in the developing world has doubled in the past 40 years and made major contributions to yield enhancement of cereals in Asia. For example, in South Asia cereal yields are typically doubled when land is converted from rainfed to irrigated. However, population growth, urbanization and industrialization trends are leading to increased water demands and competition with agriculture for water resources.

At the same time, irrigated environments face increased competition for water but also reduced water supplies due to system degradation and reduced investments in infrastructure development. For Asia, which dominates the developing country irrigated area, there has been a sharp decline in investment in canal infrastructure in recent decades (Rosegrant and Svendsen, 1992). This has been partly compensated for by the rapid spread of tubewell water in many areas, especially Eastern India and Bangladesh, although the overall growth in irrigated area has declined slightly, especially in China (table 8). The most important causes of this decrease are the long-term decline in cereal prices, the increasing real costs per hectare of new irrigation development, and heightened environmental concerns about large-scale irrigation projects (Rosegrant and Pasandaran, 1990).[2] The problem of declining investments in expanding irrigation area is exacerbated by the poor maintenance of much of the existing irrigation infrastructure, despite a relative shift in overall irrigation investment in the 1980s from new construction toward rehabilitation, operational efficiency, and maintenance. In addition, in many areas dependent on groundwater, over-exploitation of groundwater reserves is a serious threat to the sustainability of irrigated areas.

There is little reason to expect a major reversal of any of these adverse influences on irrigation investment. A sharp slowdown in the expansion of irrigated area can be expected over the next decades, with a projected annual growth of irrigated area of only 0.6% to 2020 (Rosegrant and

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[2] Compared to the late 1960s, the estimated investment costs per hectare of land for recent years has more than doubled in many areas. Today, large-scale irrigation development in Asia can cost anywhere from US$ 3,000 to USD 6,000 per hectare, which could once again double by 2025. Investment costs in Sub-Saharan Africa exceed $ 10,000 per ha.

Table 8. *Growth rate (%/yr) of irrigated area in developing and developed countries.*

Region / Country	1967-1976	1977-1986	1987-1996	1961-1996
China	2.35	–0.12	1.35	1.32
India	2.71	1.92	3.21	2.28
South, East, & Southeast Asia, less China, India	2.27	1.21	2.06	1.82
West Asia and North Africa	1.82	2.25	2.58	1.83
Latin America	3.30	1.48	2.26	2.34
Sub-Saharan Africa	1.79	2.14	1.11	1.90
All developing countries less China, India	2.00	2.06	1.91	1.96
All Developing Countries	2.28	1.40	2.12	1.86
All Developed Countries	1.02	0.91	1.19	1.29

Ringler, 1997). Globally, water is becoming an increasingly scarce commodity – one quarter to one fourth of the developing world population will face severe water scarcity in the next 25 years (Seckler, Molden, and Barker, 1998). The net effect will be increasing real costs of water at the farm level and declining *social* profitability of irrigated agriculture taking into account all maintenance and environmental costs.

Fertilizer

Fertilizer consumption in developing countries exploded in the years after 1960. Aggregate application rates over all developing countries were lower than 10 kg/ha in the early 1960s, and stand at over 90 kg/ha today (table 9).[3] Developing countries now account for over 60% of world fertilizer consumption, compared to 1960 when fertilizer was only used on a significant scale in parts of East Asia. These aggregate figures, however, conceal wide differences across regions and time periods. In high income countries in the aggregate, nutrients applied per harvested hectare reached a level of about 200 kg/ha in the early 1970s and have remained at more or less the same rate since then. In the transitional economies of Eastern

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[3] "Fertilizer" refers to the total consumption of the three major nutrients nitrogen, measured as units of N, phosphorus, measured as units of P_2O_5, and potassium, measured as units of K_2O.

Table 9. *Fertilizer consumption per harvested hectare.*

Country / Region	Average dose		Growth rate	
	1961-63 (kg/ha)	1987-96 (kg/ha)	All 1961-96 (%/year)	Last decade 1987-96 (%/year)
China	7.1	201.7	9.6	3.6
India	2.8	74.8	9.3	3.1
South, East, and Southeast Asia except China and India	11.9	89.7	6.3	2.9
West Asia/North Africa	9.9	77.2	6.8	–0.6
Sub-Saharan Africa	4.6	12.4	3.1	–2.8
Latin America	14.5	76.3	4.9	1.0
All Developing Countries	7.5	91.3	7.5	2.2
Transitional economies[a]	27.6	48.9	2.7	–19.2
High-Income Countries	120.3	197.6	1.1	–0.8
World	33.8	105.2	3.4	–1.9

[a] Includes Eastern Europe and the former Soviet Union.

Europe and the former Soviet Union, fertilizer application rates grew very rapidly up to the late 1980s, at which time nutrient application per hectare was nearly as high as in the high income countries. However, between 1988 and 1994, with the reduction in subsidies and the transition to market economies, fertilizer consumption in these countries collapsed, to application rates only one-quarter the level they were at their peak.

In developing countries, the most rapid growth in per hectare fertilizer consumption has been in Asia, where it has accounted for at least half of the yield growth over recent decades. In China, the most intensively cropped area of all the major world regions, rapid growth in fertilizer consumption has meant that fertilizer use is now comparable to those in the high-income countries and continues to climb. Growth in fertilizer use has also been rapid in India but starting from a low base – fertilizer use is only now approaching the developing country average.

Sub-Saharan Africa provides a striking contrast – fertilizer use is only about 12 kg per harvested ha. Despite these low levels, application rates in African countries have *fallen* significantly in the past decade, with economic restructuring, reduction in subsidies, and the withdrawal of the public sector from distribution.

In high income countries or countries such as China where the use of inorganic fertilizers is high, two types of concerns have recently gained prominent attention. The first is on-farm productivity concerns about fertilizer use due to declining marginal returns to further increases in fertilizer doses and the substitution of inorganic for organic sources of fertilizer. In advanced post-green revolution areas,[4] such as the Punjab of India, Java, and much of China, fertilizer use on rice and wheat (table 10) equals and in some cases surpasses the level recommended by research and extension packages (and on an annual basis, is higher than the level used in Iowa, USA). In addition, in China and other countries, the use of organic sources of nutrients has fallen as inorganic fertilizer use has expanded. Although there is little direct evidence that the substitution of inorganic for organic sources of nutrients has so far limited agricultural productivity, long-term soil health is a concern (see below). The second set of issues relates to environmental pollution arising from off-farm nutrient runoff. This issue has received particular attention in high income countries but is also a growing concern in advanced post-green revolution areas of Asia, especially where it involves the contamination of groundwater. Responding to the above concerns, fertilizer use has leveled off and in many high income countries is declining as regulations on fertilizer use tighten and more balanced integrated nutrient management becomes more widely used. This decline in fertilizer use has been achieved without negatively affecting yields, and in many cases, with increased yields.

It is clear that increased use of inorganic fertilizer will be a vital contributor to meeting required yield gains in developing countries over the coming decades. However, it will play a much smaller role than it has in the past 30 years. IFPRI projects that fertilizer use will grow by 2.2% annually to 2020 in developing countries (Rosegrant, 1998). Increased fertilizer use and greater attention to organic sources of nutrients are especially critical in Sub-Saharan Africa where increasing population density and reduced fallow periods is exacerbating an already serious problem of soil fertility.

In all regions, agricultural policy, as well as issues of infrastructure and institutional development, will be increasingly important in the coming years to support balanced fertilizer growth. On the technical side, more attention must be paid to fertilizer management, management of organic nutrient sources, and discovering the appropriate nutrient balances, in order to enhance efficiency. Policy and institutional support will be impor-

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[4] In this paper, advanced post-green revolution areas are defined as those areas that first experienced the widespread adoption of high-yielding varieties and where input use is now high, close to that recommended in the package.

Table 10. *Trends in yields and fertilizer use in advanced post-green revolution areas.*

	Rice Indonesia	Rice, Indian Punjab	Wheat, Indian Punjab	Wheat, Pakistan Punjab
Average for period	1991-93	1991-93	1992-94	1992-94
Fertilizer (kg/ha)	140	186	205	124[a]
Yield (t/ha)	4.4	5.1	3.8	2.1
Growth rate for period	1986-93	1986-93	1986-94	1986-94
Fertilizer (%/yr)	0.4	2.2	0.6	1.2[a]
Yield (%/yr)	0.5	1.1	1.5	1.3

[a] All Pakistan.
Source: Byerlee, 1998.

tant to developing fertilizer markets in those areas where fertilizer use is still low – much of Sub-Saharan Africa. In the past also, fertilizer use has been stimulated by a long-term downward trend in real prices due to technical change in the fertilizer industry. Most observers believe that there is little reason to expect a reversal of these trends in the medium term, although fertilizer prices, as in the past, will continue to be highly volatile. In the longer term, of course, fertilizer prices are subject to potential worldwide increases in energy prices.

Pest control

From less than US$ 1 billion in 1960, the global agricultural pesticide market was valued at US$ 30 billion in 1995 (about 2 million t of active ingredients), indicating an annual growth rate of almost 11 per cent. Cereal crop production is the second largest consumer of agricultural pesticides, next only to that of fruit and vegetable production. Within cereals, rice in Asia and maize in industrialized countries are the largest consumers (about 23% of the total). However, the composition of the pesticide market has been changing in recent years. Total insecticide use for rice production, for example, actually decreased by 10 per cent from 1989 to 1993 while the proportion of herbicides in total chemical use increased from 27 per cent to 35 per cent (table 11).

Table 11. *Percentage change and annual growth rate of sales in pesticides used in rice production in selected Asian countries, 1980-1993.*

	Percentage Change			Annual Growth Rate	
	1980-84	1985-89	1990-93	1981-86	1987-92
Bangladesh					
Insecticides	...	–37.5	–66.7	...	–6.3
Herbicides	...	0.0	–66.7	...	–6.1
Fungicides	...	33.3	–47.4	...	6.8
China					
Insecticides	109.1	17.9	–8.6	12.0	4.4
Herbicides	40.0	–37.5	...	9.0	...
Fungicides	31.6	0.0	22.2	1.2	2.1
India					
Insecticides	175.0	13.8	–28.6	8.5	4.4
Herbicides	62.5	53.3	–17.9	9.3	9.4
Fungicides	14.3	33.3	25.0	0.4	11.9
Japan					
Insecticides	62.3	51.9	1.4	14.6	–1.1
Herbicides	6.8	–53.4	14.6	11.6	1.0
Fungicides	3.1	16.6	34.6	11.0	1.9
Philippines					
Insecticides	37.5	–40.0	–21.0	7.4	0.0
Herbicides	125.0	40.0	–21.4	17.6	2.5
Fungicides	0.0	83.3	–78.6	1.1	12.0
Myanmar					
Insecticides	4.0	167.9	36.2	7.3	15.5
Herbicides	0.0	83.3	155.8	16.0	31.6
Fungicides	0.0	191.7	–6.8	8.7	9.9
Vietnam					
Insecticides	20.0	–16.7	58.3	3.3	10.4
Herbicides	...	20.0	–50.0	...	0.0
Fungicides	...	150.0	–58.3	...	13.6
All Asia					
Insecticides	77.9	36.4	–10.4	11.5	3.3
Herbicides	23.0	46.0	24.4	13.0	3.7
Fungicides	12.8	35.5	10.2	9.4	4.2

Source of basic data: World Rice Statistics 1993-94 (IRRI, 1995).
...= No data available.

Intensive rice mono-culture systems, made possible by early maturing varieties and irrigation, created an environment that was conducive to pest growth. Although pest-related yield losses were small in percentage terms, they were highly visible and led to apprehensions by policy makers of major outbreaks. Pesticides were seen as a complement, both as a guarantee against crop failure and as a means of fully utilizing the existing yield potential of the crops (Waibel, 1986).

Indiscriminate and injudicious use of agrochemicals was directly the result of inappropriate or inadequate pesticide policies in developing countries that made pesticides easily accessible and affordable at the farm level without sufficient safeguards on safe pesticide use (Pingali and Rola, 1995). In the past decade, a more enlightened policy towards environments along with the introduction of crop varieties resistant to insects and diseases, and the promotion of integrated pest management, have resulted in the beginning of a downward trend in pesticide consumption, the use of safer chemicals, and improved farmer safety and environmental sustainability.

As discussed above, host-plant resistance has been the cornerstone of the scientific strategy for developing sustainable pest control systems for all major cereals (table 12). In rice – the major user of pesticides on food staples in developing countries – on-farm experiments and farm yield surveys do not support yield or profitability response to pesticide applications on currently available resistant rice varieties.[5] The introduction of newer generations of resistant varieties combined with other integrated pest management practices has dramatically reduced the need for insecticides in cereal crops, often resulting in increased yields as well.

The one area where agro-chemicals continue to have a significant productivity impact is in the management of weeds, although the effect is usually more labor saving than yield enhancing. The use of herbicides is expanding with the general rise in farm wages, particularly in Asia, and the growth of zero tillage practices throughout the world. Herbicides will become the preferred alternative in an increasing number of food production systems in the developing world. Even in areas where wages are relatively low, such as Sub-Saharan Africa, herbicide use is likely to expand with the adoption of chemical (zero) tillage which is already underway in a number of countries.

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[5] Profitability becomes even greater when the health costs of exposure to insecticides are explicitly accounted for, because the positive production benefits of applying insecticides are overwhelmed by the increased health costs. Recent studies in the Philippines have shown that the value of crop loss to pests is invariably lower than the cost of pesticide-related illness (Rola and Pingali, 1993) and the associated loss in farmer productivity (Antle and Pingali, 1994).

Table 12. *The evolution of host plant resistance for the major cereals.*

Period	Rice	Wheat	Maize
1960s	Striped stemborer	Stem rust	European corn borer
1970s	Brown planthopper Green leafhopper Rice whorl maggot	Septoria triticiblotch	Ear worms Tropical borers Southwestern corn borer
1980s	Yellow stemborer White-backed brown planthopper Thrips	Leaf rust	Fall army worm
1990s	Bacillus thuringiensis	Spot blotch Fusarium scab Stripe rust	Bacillus thuringiensis

Negative influences on cereal yields

The rapid increase in crop yields in recent decades is not all good news, however. There has been growing concern that increased yields associated with intensification have been at the cost of degradation of the natural resource base. In some areas part of this degradation is due to the ecological consequences of intensification through the use of modern inputs and the widescale mono-cropping of cereals, as legumes and other crops have been pushed out of cropping systems. This is reflected in a multitude of emerging problems in the form of declining soil fertility and health, soil salinity and waterlogging in irrigated areas, over-exploitation and pollution of groundwater, to overuse of agrochemicals and adverse effects of pesticides on the health of farm workers. In other areas, degradation is due to intensification *without* the use of modern inputs leading to a situation of soil nutrient mining.

There is as yet no consensus on the severity and scale of these problems, and their implications for the sustainability of future crop yield growth. Some authors argue that on a global scale soil degradation is having relatively minor effects on aggregate yields (e.g., Crosson (1995) who estimates an overall annual yield loss of 0.11%). However, for two major developing regions – the intensive irrigated cereal monocrop systems of

Asia, and the medium to high population density regions of Africa – the evidence suggests that there are indeed serious problems of sustainability.

The evidence for degradation of some intensively cropped cereal systems of Asia has been extensively documented (Pingali, Hossain, and Gerpacio, 1997; Byerlee, 1992, Ali and Byerlee, 1998, Huang and Rozelle, 1995). This degradation is reflected in declining yields in long-term experiments, increased use of inputs to achieve the same yields in farmers fields (as expressed in total factor productivity measures), and in indicators of soil, water and human health.[6] Degradation appears to be most severe in the monocrop cereals systems, where rice is continuously cropped or rotated with wheat. Although the technical relationships are still imperfectly understood, most degradation relates to a complex of physical, chemical and biological changes in soil health. Unfortunately there are few long-term data series on soil testing to document these changes and even less analysis of their quantitative effect on productivity. One exception is a recent study in Pakistan's Punjab, which estimated that soil degradation has reduced productivity growth since the green revolution by one third and in the case of the rice-wheat system, has completely cancelled the positive productivity effects of technical change (box 1). A similar study in China, however, found much smaller effects on productivity (Lindert, 1996).

While resource degradation is increasingly observed in intensively cultivated systems, intensification *per se* is not the root cause of environmental and ecological damage. Rather, degradation occurs mainly when incentives encourage monocropping at the expense of more diverse rotations (e.g., due to lack of attention to legumes) or inefficient input use (e.g., pricing policies that undervalue water). In many cases too, both scientists and farmers lack sufficient knowledge of the underlying processes of degradation to design appropriate strategies to arrest degradation. As developing countries liberalize their agricultural sectors and move away from the single-minded pursuit of cereal self sufficiency one can expect positive resource and environmental benefits. Investment in crop and resource management research will also be an essential component of the strategy (see below).

By contrast, soil degradation in Africa is directly attributed to the *low* use of external inputs. In many areas, intensification has been driven by rapid population growth and breakdown of the traditional bush-fallow method of maintaining soil fertility, with shortening or even elimination of the fallow period with growing land scarcity. In these areas there is wide-

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[6] Monocropping has also reduced onfarm diversity, although the loss of biodiversity due to planting of genetically uniform varieties over large areas is less of a problem than commonly believed (Smale, 1997).

spread evidence of soil nutrient mining, and eventual degradation of soil physical properties through reduction of organic matter (e.g., Kumwenda *et al.*, 1997). At the same time, poor infrastructure and lack of development of both input and output markets has limited the use of inorganic fertilizers, while use of organic sources of nutrients is constrained by lack of appropriate technologies, labor constraints and shortage of livestock in the system. The result is a serious problem of soil fertility and often other forms of soil degradation, especially soil erosion. In many areas the effect is seen in a switch from cereals to other food staples, such as cassava, which is more productive in infertile soils.

The reversal of these trends requires an approach that integrates the efficient use of inorganic fertilizers with the exploitation of organic sources of nutrients, rotation with legumes, improved fallows through green manuring and agro-forestry, often combined with efforts to protect soil cover and runoff, such as conservation tillage and physical and vegetative barriers to soil runoff. These efforts will have to be backed by concerted support from research and extension, investment in infrastructure and market development, and in some cases, appropriate incentives for recapitalizing soil fertility.

FUTURE PROSPECTS FOR YIELD GAINS

We now discuss future prospects for yield gains into the early twenty-first century in three contrasting situations; (i) advanced areas with high yields and a low yield gap (mainly in Asia), (ii) favored areas with a significant yield gap (e.g., much of rainfed South Asia and Sub-Saharan Africa), and (iii) low potential areas with low yield gaps with current technology (e.g., the African Sahel). The analysis shows that significant yield growth is possible in all three situations, but the strategies required to achieve that growth will differ significantly by area. The greatest potential gains can be made in the favored rainfed areas. Fortunately, these areas also constitute a large share of developing country agriculture.

Advanced areas – high yields and low yield gap

In the advanced post-green revolution areas across Asia, such as the Indian Punjab, much of China, Central Luzon in the Philippines, much of China and Egypt, and irrigated north-west Mexico, the economically exploitable gap between experiment station yields and farmer performance, at minimized agroclimatic and biophysical differences, is now very small. (box 2).

It is clear that the first priority in these areas is to shift the production frontier upwards and break the yield plateau through increased investments in agricultural research, especially upstream research in breeding, crop physiology, and molecular biology. Recent technological breakthroughs promise much. Exploitation of heterosis through hybrid varieties is now well under way. Nearly half of the maize area in developing countries is sown to hybrid maize. Hybrid rice, popularized in China, is now being adopted in other irrigated areas of Asia. Within a decade, varieties and hybrids with sharply modified plant architecture should be available to significantly boost yields, such as the new plant types for rice and wheat now under development in IRRI and CIMMYT.[7]

The new tools of biotechnology combined with basic research in the plant sciences to improve biological efficiency, pest resistance and tolerance to abiotic stress (e.g., drought and heat) could, with sufficient investment in research, also provide high payoffs over the next few decades in advanced areas (Evenson, Herdt and Hossain, 1996). Genetically engineered rice and maize with new sources of resistance to several major pests are expected to be available to developing-country farmers within the next few years. However, concerns that transgenic plants could have negative effects on human health and the environment, and in many cases lack of national-level biosafety and intellectual property rights regulations, are slowing the field testing of these products. In addition, there is concern that both international and national research centers are investing insufficient resources in basic plant sciences to enhance biological efficiency (Ruttan, forthcoming; Evenson, 1998).

There are also considerable opportunities to raise productivity in advanced areas by exploiting the large technical efficiency gap now observed in these areas (Byerlee, 1992). Many areas could produce the same or higher yields with lower input costs through practices designed to enhance input efficiency.[8] Many incremental management changes, often very knowledge intensive, relating to site- and season-specific pest, water,

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[7] In the medium term for rice, yield increases of around 20 per cent could be possible through the adoption of hybrid rice (Virmani *et al.*, 1994). The longer term prognosis is for a "new plant type" that could yield about 12.5-13 t ha^{-1} and, as a parent of the hybrids, could increase this yield to 15 t ha^{-1} of grain (Khush, 1995).

[8] Most analysts conclude that the potential to increase input efficiency at this stage of growth is substantial. Agronomists, by carefully measuring nutrients applied and taken up, have documented that nutrient use efficiency is very low at the farm level. Economists, by constructing a production frontier across a sample of farmers, have observed that many farmers operate well below the possible frontier (by an average of about 30% – see Hussain and Byerlee, 1995, for a review of the evidence).

and nutrient management, provide the potential for reducing this efficiency gap, but as elsewhere this type of "precision farming" will require greatly improved knowledge transfer systems and skilled and educated farmers to be successful (discussed below).

The third part of a strategy for advanced areas must be to sustain productivity gains and arrest the degradation of the resource base. The favorable irrigated environments will continue to be the primary source of food supply for developing countries of Asia and it is imperative that long-term solutions to sustain the productivity of these lands is found. Many of the degradation problems observed in the intensively cultivated irrigated environments are reversible. The problem of sustaining productivity growth comes about because of inadequate attention to understanding and responding to the physical, biological and ecological consequences of agricultural intensification. The focus of research and policy ought to be on shifting away from a fixation on yields and input use to a holistic approach to the long term management of the agricultural resource base. This includes removal of subsidies and taxes that distort incentives; the establishment of secure property rights; investments in research, education and training and public infrastructure; and better integration with international commodity markets.

Favored areas with significant exploitable potential

In the best areas considered in the preceding section, yields on farmers' fields are usually 70 per cent or higher of the levels attained on research stations. In contrast, in most parts of the world, particularly large parts of Africa, but also significant rainfed areas of Asia and Latin America, farmers' yields may only be 35-45% of the yields obtained on station or in researchers' trials in farmers' fields and there is often a wide yield spread among farmers (e.g., Hassan 1998; Byerlee and Lopez-Pereira, 1994). In some regions of Africa where farmers are using no "modern" inputs, their yields may be even lower, falling under 20% of those on station (Heisey and Smale, 1995). These areas are rainfed, and moisture availability, although quite variable, is not the major limiting factor on yields in most years. Further, soils may be inherently relatively poor in nutrients. However, the widespread large yield gaps suggest there is significant unexploited potential for raising yields on farmers' fields.

Low population densities in some of the more favored but unexploited areas have meant that, until recently, there was less need to intensify agriculture. Populations are growing extremely rapidly, however, so that today much of eastern Africa, parts of southern Africa, and individual West

African countries like Nigeria have densities comparable to those in rainfed Asia. It is clear that in such areas (and in other higher potential rainfed areas such as some parts of the Indian subcontinent – see Hazell and Fan 1998), input intensification is going to be the key to necessary increases in food production, just as it was in advanced areas. For several reasons, however, the path to input intensification and higher yields in favorable regions with a large yield gap is likely to be more difficult than in the early "green revolution" areas.

In rapidly intensifying agriculture, soil fertility degradation can become a particularly important problem (Blackie, 1995). For production systems that have yet to undergo significant input intensification, a balance must be developed between input intensification and enhanced input efficiency and sustainability. This is particularly important in sub-Saharan Africa where some advocate the development of environment-friendly technologies, such as internal sources of nutrients that use low or no external inputs in order to bypass the input intensification stage. While there is an urgent need to increase research on systems relying on greater use of organic sources of nutrients that may enhance sustainability over the long run, it seems unlikely that productivity can be increased sufficiently rapidly without a strong effort to encourage the adoption of external inputs, especially chemical fertilizers. In Africa, however, use of fertilizer has been constrained by particularly high prices and shifting levels of availability, a result of many factors including lack of infrastructure and insufficient market development (Heisey and Mwangi, 1997). Furthermore, conditions in favorable but unexploited rainfed areas tend to be more variable than in advanced irrigated areas. Blanket recommendations for fertility and other crop management practices, though not necessarily "optimal" in advanced areas, were nonetheless quite serviceable there. In favorable rainfed areas, the need for information-intensive management technologies to adapt to location- and season-specific conditions, is likely to appear earlier in the intensification process than it did in advanced areas.

Whatever approach (or combination of approaches) to intensification is used, one of the easiest and most obvious sources of productivity increases are the genetic gains associated with the continuous release and widespread adoption of new generations of input-responsive MVs. These enhance the efficiency of nutrient use, whether internally generated or purchased externally. For the most part they also provide greater resistance to diseases and pests. For maize, the major food crop in much of this area, there is considerable scope to shift the yield frontier, given the experience and scientific knowledge available in industrialized nations. In many areas, private seed companies may be willing to make the necessary investments given the appropriate institutional environment. However, technology transfer between temperate and tropical environments for maize requires considerable investment in research to adapt to tropical conditions. Also, multinational private seed companies that dominate maize hybrid research in industrialized countries may hesitate to enter markets characterized by relatively large numbers of small farmers; smaller indigenous private companies with access to good publicly developed germplasm may potentially be more successful in earlier stages of seed industry development (Morris, 1998).

In summary, there is large potential in many favorable rainfed areas to significantly increase crop yields (box 3). For this to happen, however, several major issues need to be addressed. First, research and extension systems must become more innovative and make use of new tools and institutional innovations to adapt technology more readily to varying farmer conditions. Second, as in advanced areas, greater educational investment is necessary to make farmers better prepared to use knowledge-intensive technologies. Third, carefully planned development of market and communications infrastructure is essential to reduce substantially the cost of supplying external inputs to farmers. Finally, institutional innovation in the seed industry will be important to make higher yielding varieties available and profitable for the food crops grown by the majority of small farmers in high potential areas.

Marginal areas – low yields and low yield gaps

Marginal areas are defined as areas where yields in most years are severely constrained by one or more climatic stresses, usually drought, often combined with a poor or fragile soil resource base and poor infrastructure. Most marginal areas in the developing world are defined by severe drought stress where yields are low and variable, and the exploitable yield gap with current technologies is also often low. These areas deserve special consideration because poverty levels are often very high and the natural resource base is often degraded. Marginal areas have benefited the least from technical progress over the past three decades. In most cases, technological solutions promoted in these areas have imitated the example of seed-fertilizer technologies that succeeded in favorable areas. However, these solutions have often been inappropriate to the complex farming systems operated by farmers in these areas, the location- and season-specific response to new practices, and the special concerns that farmers in marginal areas have for food security and risk avoidance.

While modern varieties, especially varieties that incorporate some tolerance to drought stress, have an important place in improving crop yields and stability in marginal areas, they usually cannot be the lead technology as in the more favored areas. The key to most of these areas is to improve moisture supply and efficiency in its use through tapping soil and water conservation technologies such as small-scale irrigation, on-site water harvesting, and use of moisture conserving tillage. For example, tubewells have spread rapidly in the dry areas of India, and the huge success of introducing small pumps in the *fadama* areas of northern Nigeria has transformed large areas there. Although farmers often use these small irrigated areas for production of cash crops, there is little doubt that the increased income generated has greatly enhanced their food security.

Substantial resources have also been invested in capturing scarce moisture in order to increase response to modern inputs, especially the use of ridges and stone ties in the Sahel of Africa (Sanders, Shapiro and Ramaswamy, 1996), and the large investments in India to promote development on a watershed basis (Kerr, Hazell and Jha, 1998). While technologically attractive, these approaches pose practical difficulties due to the requirement for collective action at the community level, and their promise has often been difficult to realize. In India, for example, a recent evaluation of watershed programs found little overall impact of most programs. Researchers and development practitioners are increasingly realizing that greater participation of intended users will be required to develop and adapt technologies to meet complex, location-specific requirements in unfavorable areas (Kerr *et al.*, 1998).[9]

Agricultural intensification in marginal areas will also require a refocusing of supporting policies and public investments. In India, there is clear evidence that infrastructure investments provide high payoffs in marginal areas (Fan and Hazell, 1998) due to lower transport costs, improved access to inputs, and increased market access for non-traditional crops. Investment in schooling will also be essential to enhance opportunities in the non-farm sector. In the past, public investment in markets and infrastructure has generally been biased toward the more favored areas.

Difficult choices: Favored versus marginal areas

We have emphasized the importance of public investments in technology, human capital, and infrastructure in order to secure needed yield

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[9] Unlike the other areas discussed above, agricultural intensification in dry areas is usually, but not always, associated with environmental improvements, rather than degradation, due to better soil coverage, soil conservation, and greater availability of organic matter and fodder through crop residues.

growth. In a climate of austere budgets and retrenchment of the public sector, difficult decisions have to be made about allocation of resources across environments of different agricultural potential, and the type of investment relevant in each environment. Figure 3 provides a stylized summary of the types of investments and key objectives of national food security (i.e., efficiency) and household food security (i.e., equity). In the advanced areas there are high payoffs to research, both strategic and adaptive, and farmers' schooling. In favored areas with exploitable yield potential, infrastructural investments are often most critical since better access to input and output markets induces intensification (Fan and Hazell, 1998). In marginal areas, infrastructure is also important, and together with investment schooling opens opportunities in the non-farm sector over the longer term. However, for the medium term, investment in research is needed to secure household food security in the absence of other livelihood opportunities (Pingali and Reeves, 1998; Byerlee, Hazell and Kerr, 1997). Investment choices in these areas should give high weight to equity concerns.

Investment in research, for example, will often require longer time frames and be more costly. In some cases, research can be made more cost-effective research where spillover benefits can be captured from research in more favorable environments. For example, wheat production in West Asia and North Africa has benefited substantially from spillover from breeding research in favored areas (Pingali and Rajaram, 1997). The international research system plays a crucial role in maximizing the spillover benefits of research on unfavorable environments across countries (Maredia and

Environment	***Major objective***	***Investment priority***	***Other priority***
High yield/ low yield gap	*National food security (efficiency)*	*Technology* *Education*	
Significant exploitable yield gap	*National and HH food security*	*Infrastructure* *Technology*	*Education*
Low yielding marginal	*HH food security (equity)*	*Infrastructure* *Education* *Safety nets*	*Technology*

Fig. 3. Stylized View of Objectives and Priorities by Environment.

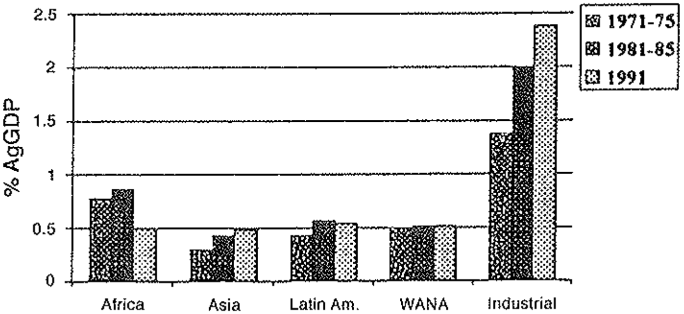
Eicher, 1995). However, when spillovers are not possible, as in many of the harshest environments, then public research investment must kick in to develop technologies adapted to the special conditions of marginal areas. Depending on the relative size and importance of the marginal environments in a particular country, research investments targeted at alleviating particular stresses can provide satisfactory returns.

INSTITUTIONAL AND POLICY CHALLENGES TO REALIZING YIELD GAINS

Investment in research

The technological challenges for raising food crop yields in the developing world, discussed above, repeatedly underline the critical importance of increasing investment in research. After growing rapidly during the green revolution period, public investment in agricultural research in developing countries has stagnated during the past two decades at about 0.5% of the value of agricultural output (figure 4) – much lower than required by industrialized countries to generate rapid technical change on a sustained basis (Alston, Pardey, and Roseboom, 1998). Although the increasing commercialization of agriculture in many countries has encouraged greater private investment in agricultural research, this is still narrowly targeted on certain types of technology, such as hybrid seed and chemicals.

Public investment in agricultural research will continue to be the major source of new technologies for most major food staples for the next two decades. Although donors and governments have invested heavily in developing national research systems, few countries yet have a productive and



Source: Alston, Pardey, and Roseboom, 1998.

Fig. 4. Agricultural Research Intensity by Region: Public Sector Only.

sustainable system capable of generating the technologies needed to ensure rapid productivity gains. Public research organizations are struggling to attract funding and become more efficient at the same time that they have to respond to a wider research agenda. The institutional environment in which they operate is also more complex with the evolving role of the private sector and the globalization of research (Byerlee, 1998).

Public sector agricultural research systems will have to clearly define research skategies that maximize their impacts but this poses a number of dilemmas. One issue is the relative emphasis to be placed on technologies that embody new knowledge, such as new seeds (e.g. varieties with enhanced input efficiency), versus "disembodied" technologies, where new knowledge is provided in the form of information on crop and resource management (e.g. integrated practices to enhance input efficiency). These alternatives involve tradeoffs, since increasing efforts to embody more traits in seed will reduce the rate at which the production frontier is pushed upward (Traxler *et al.*, 1994). On the other hand, the cost and technical skills involved in transferring and adopting seed technologies is small compared to that required for integrated crop management technologies which require the packaging and transfer of large amounts of technical information.

In the past, highest priority was assigned to plant breeding and crop protection research – by 1990, the level of investment in varietal improvement research for wheat and maize in developing countries (expressed in terms of numbers of scientists per million tons of crop output) was higher than in industrialized countries (Maredia and Eicher, 1985; Byerlee and Lopez-Pereira, 1994). In contrast, investment in crop and resource management research has lagged, research quality is often low, and payoffs have not been obvious. Yet it is clear that a more holistic and integrated approach to crop and resource management research will be a high priority for increasing future yields in both high- and low-yielding environments. Multidisciplinary, systems-oriented teams of researchers must work with farmers to explore innovative crop and resource management technologies in order to generate the types of flexible solutions that are needed to allow farmers to meet their own particular circumstances (Hobbs and Morris, 1996).

The need to invest more in basic and pre-breeding research which is largely a public good in order to push out the yield frontier further reinforces the key role of increased public investment in research. Basic and strategic research to enhance biological efficiency requires a concerted global effort involving advanced research institutes in the industrialized and developing world, international agricultural research centers, and national research systems. On the other hand, much of the crop and resource management is very location specific, requiring substantial investment at the national and even local levels.

Intellectual property rights and biological technologies

With the strengthening of intellectual property rights legislation for biological technologies and processes around the world, there is a rapid move in both the private and public sectors of industrialized countries to protect plant varieties. The effects of these trends are still uncertain but must be monitored closely. The success of plant breeding over the past three decades has been highly dependent on the free and unhindered access to improved germplasm worldwide. The current flurry of patenting activity may cause a disruption in the established international flow of germplasm as breeders become less open in sharing breeding lines. Also, public breeders are being tempted to duplicate private sector efforts in varietal development at the expense of focusing on essential public good activities such as pre-breeding research and genetic conservation that hold little potential for generating patentable discoveries. This is a potentially serious threat to genetic improvement, since as we have seen, many observers already consider investment in more basic genetic enhancement research to be inadequate.

On the other side, improved intellectual property protection is undoubtedly encouraging a increase in private sector investment in agricultural research. While these efforts have focused to date on industrialized countries, private sector research in developing countries is increasing rapidly, especially in Latin America and parts of Asia (Pray and Umali-Deininger, 1998). The private sector already plays a dominant role in varietal improvement in maize in developing countries and its role in several other food crops is also expanding. However, proprietary technologies in developing countries are still largely being protected through trade secrets (i.e. use of hybrids), and it is not clear under what circumstances it will be feasible and cost-effective to enforce property rights for open pollinated varieties grown by small-scale farmers.

Balancing commodity priorities; Re-incorporating legumes into cropping systems

A further critical choice is the relative priority to major cereals versus secondary foods. In our opinion, there are critical roles for food legumes that merit priority in future strategies for sustainable yield growth and food security. Re-incorporating legumes into cereal-systems offers a viable strategy for reversing the current trend toward monocropping while sustainably intensifying food production and enhancing human nutrition.

There are several priorities for reinstating the role of legumes (Byerlee and White, 1997). First, policy makers and the farming community in general must be made aware of the lack of sustainability of many cereal-based cropping systems. Second, imaginative leadership is required of scientists, farmers and policy makers to identify new niches within existing systems for incorporating legumes varieties. Third, researchers face the challenge of developing improved food legume varieties to fit cropping systems, especially early maturing varieties which allow greater flexibility to intensify cropping patterns. Better targeting of consumer preferences, reducing yield variability through breeding for biotic and abiotic stresses, and enhancing nitrogen fixing capacity, pose further challenges in developing more acceptable food legumes. Fourth, while food legumes are increasingly produced in marginal areas, the greatest potential for their future expansion is likely to be in more favored growing areas from which they have been displaced. Food legumes may be incorporated into these areas as rotation crops with cereals or within various multiple-cropping systems. Finally, removing policy distortions in favor of major cereals, such as market support, input subsidies and special extension programs promoting only cereals, is a critical step to leveling the playing field for encouraging food legumes.

Precision management for small-scale farmers

Information-intensive technologies (IIT) – integrated crop management as applied to nutrients, crop protection, or water management – have substantial potential to enhance productivity growth as well as to contribute to more sustainable production systems. Examples of efficiency-enhancing technologies are: improved varietal selection; zero tillage, improved timing and application systems for fertilizers; integrated pest management; and judicious water management. This technology is provided in the form of complex management information that will require farmers to have a much broader array of information, scientific principles, and skills – often called precision agriculture. Emphasis must be on increasing farmers' *demand* for information and their ability to process information for their specific situations, and to quickly update information in response to changing conditions and opportunities.

Several features will dominate research and technology transfer for IIT. On the one hand, this type of research will need to be decentralized and strongly oriented toward farmers. Greater farmer participation through control by local farmer groups, and partial financing of research and extension advisory services at the district level, will be needed to ensure local accountability. A further challenge is to find cost-effective methods for transferring knowledge intensive crop management technologies. Knowledge transfer requires that farmers adapt scientific principles to their own particular circumstances and derive field and season-specific practices. The use of decision aids such as soil and tissue tests or pest scouting is an integral part of the strategy to transfer IIT. The complexity and the costs associated with training programs that try to incorporate the above features are very high and often act as impediments to action on the part of advisory services. Greater farmer participation and empowerment will be needed to efficiently adapt and transfer these technologies and to share the cost of these activities.

On the other hand, researchers, extensionists and farmers will have to employ state-of-the-art informational technologies, such as crop models, geographical information systems, and expert systems, to account more effectively for spatial and temporal variability in the many variables that condition optimal crop management. While the ownership of computers by the mass of the farming population of the developing world is still in the distant future (awaiting lower cost computer technologies and higher income, better educated farmers), rural communities will increasingly have access to this technology that will allow direct electronic communication with technical specialists and access to the vast information resources on the internet. The effective use of these technologies will place a premium on literacy and education levels, increasing the payoffs to public and private investment in formal education. To date, this coming information revolution in developing country agriculture has received too little attention from scientists and policy makers.

Labor-saving versus land-saving technology

Yield growth, the subject of this paper, is usually associated with land-saving technologies, such as seed and fertilizer. The adoption of labor-saving technologies has generally been associated with land abundance and good access to markets, domestic as well as international. Production growth in such environments has often resulted from area expansion made possible by mechanization. However, the dichotomy of choice between land- and labor-saving technical change has become blurred in recent decades, especially in the rapidly growing economies of Asia. Rapid growth in the non-agricultural sector as well as the transition from rural to urban based populations has resulted in an escalation of the opportunity cost of labor and hence the rise in demand for labor-saving technologies. Widespread adoption of labor-saving mechanical and chemical technologies has alleviated the growing labor constraints, and contributed substantially to overall productivity growth.[10] In the future a more balanced approach

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[10] Japan for instance, shows almost no increase in land productivity but substantial gains in labor productivity during the last thirty years (Hayami and Ruttan, 1985).

between land-saving and labor-saving technologies will be required in designing research, extension and investment strategies.

Supportive policy environment

Finally, agricultural policy must support the adoption of practices which substitute improved information and management for further intensification of input use, and promote conservation of natural resources. Continued subsidies on many inputs and outmoded pricing structures for inputs, especially water, have long outlived their usefulness and are now part of the problem of resource degradation. Subsidies on inputs need to shift to subsidies on information technology, in the form of public awareness efforts, training programs in the new technologies (e.g., IPM), and incentives for community investment in information technologies and decision aids at the village level. Supporting institutional reforms will also be important – for example, the greater devolution of water management decisions to users, and a gradual shift to market-determined water allocation systems.

Finally, overall efficiency and effectiveness of technology generation and transfer can be enhanced by liberalization of policies on the importation and release of new technologies. This includes elimination of bans on imports of improved seed, more reasonable phytosanitary requirements, and more open and liberal in-country testing procedures for release of these technologies. Local research programs can become more efficient in developing improved agricultural technologies if they allow for technologies developed elsewhere to be tested in their countries and permit those which adapt well to be used by local farmers.

CONCLUSION

The challenge of maintaining adequate crop yield growth into the first half of the next century is difficult but quite within the capacity of current scientific knowledge. In most of the developing world the scope for progress in technological change in food production is substantial. Strategic decisions will have to be made regarding the optimal roles for the public and private sector and their respective clients, the mix of agricultural policy measures needed to foster development of the food crop sector, the priority to agricultural production environments with different potential, and the relative emphasis on crop breeding versus crop and resource management. As practical applications of new scientific knowledge appear, many opportunities will appear as well. Success will depend on developing a responsive research system, and finding an appropriate balance on productivity increases, so that important issues such as sustainable resource management, meeting the evolving needs of small scale farmers, and resolving the legal requirements of diffusing proprietary technologies in developing countries, receive priority attention.

In conclusion, there are many technological opportunities for increasing crop yields over the next decades. While the agricultural development community has been enormously successful over the past 30 years in increasing crop yields, it is clear from this review that future increases will not be "more of the same". Indeed, there is no single evident path to these increased yields – yield growth will be the sum of many small changes in practices whose choice will be much more location specific. Success will depend on continued research investment and appropriate policies. Yield gains are likely to be costlier to achieve than in the past thirty years. On the positive side, many of the new sources of yield growth surveyed in this paper show promise to increase productivity in a more sustainable manner. There are also still large areas of the developing world with low yields and a large exploitable yield gap.

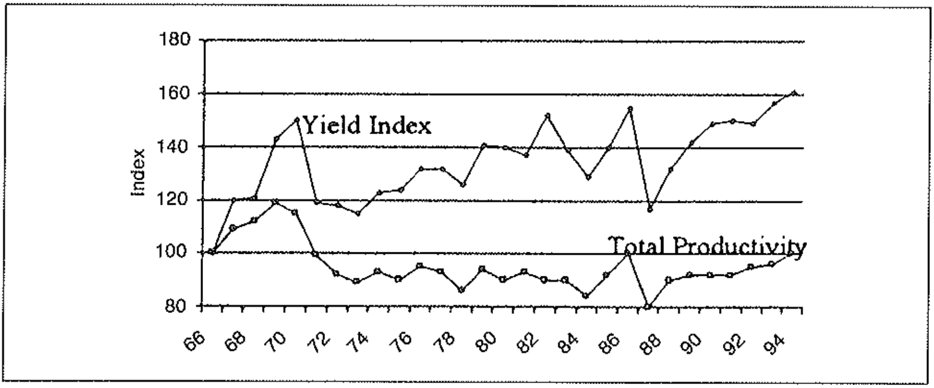
Provided that the world research community continues to integrate, at the same time that developing countries make strategic decisions on research capacity development, crop yields should be able to meet projected demand well into the twenty-first century. These projections are also based on the assumption that public institutions at the national and international levels receive substantially more financial support than in the recent past so that they can face these challenges and respond to new opportunities. Whether or not this results in improved welfare for the poor and reduced levels of environmental stress depends as much on appropriate policies as it does on the technological change itself.

BOXES – CASE STUDIES ON CLOSING THE YIELD GAP AND MAINTAINING PRODUCTIVITY GAINS

Box 1: *Productivity and sustainability in monocrop cereal systems in Pakistan*

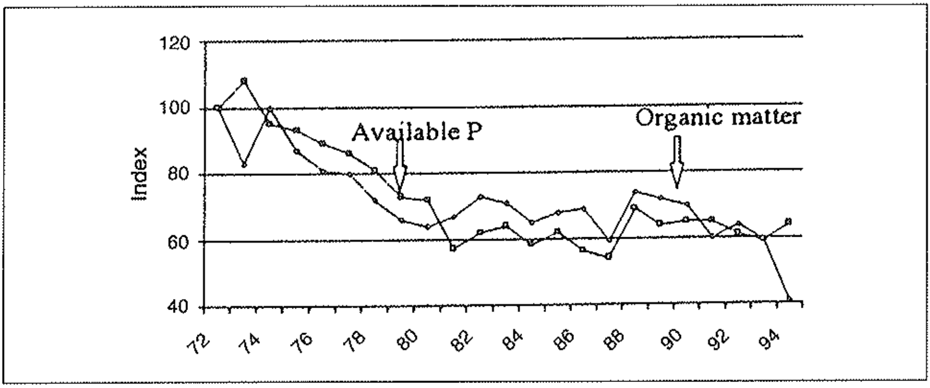
Pakistan's Punjab province is the agriculturally dominant province in the country, with a farming population of over 60 million people, and is often described as Pakistan's bread basket. Largely irrigated, the Punjab was one of the earliest beneficiaries of the green revolution with the introduction of modern varieties of wheat and rice in the 1960s. However, recent studies have questioned the sustainability of current intensification strategies – crop yields have grown very slowly despite the continuous adoption of newer generations of improved varieties and further intensification.

The results of a recent study by Ali and Byerlee (1998) confirm that resource degradation is a serious problem in the monocrop rice-wheat system. Detailed soil and water test data were collected over a 25 year period for each major cropping system and then related to indices of total factor productivity (i.e., the change in output in relation to all inputs). Total factor productivity was found to have grown by 0.8% annually in the rice-wheat system compared to double that in the cotton-wheat system (figure 5 for rice-wheat). More importantly, soil and water test data indicate a continuous decline in soil and water quality as indicated by organic matter, soil



Ali and Byerlee, 1998.

Fig. 5. Trends Productivity: Pakistan Rice-Wheat.



Ali and Byerlee, 1998.

Fig. 6. Trends in Selected Soil Test Data Pakistan Punjab.

phosphorus and salt content of soil and tubewell water (see figure 6 for soil data). These problems are most severe in the rice-wheat system and are large enough to have negated the effects of technical change. Finally, both investment in infrastructure (rural roads) and farmer schooling were found to make significant contributions to productivity growth in all systems.

Box 2: *The Philippine farmer and the irrigated rice yield gap*

Farmers in the neighborhood of IRRI in Laguna and Philippine Rice Research Institute (PhilRice) in Nueva Ecija were monitored over a two-decade period. Experimental yield potential data from the IRRI farm was compared with the farmer sample in Laguna, while the yield potential data from PhilRice was compared with the Nueva Ecija farmer sample.

These comparisons reveal a yield gap of around 1.2 t ha^{-1} which has consistently declined over time. However, further analysis reveals a more complex picture. In 1966 the gap between the IRRI farm and the top third of the Laguna farm yields was approximately 2.2 t ha^{-1}. This gap declined rapidly and by 1978 the top third yields on the Laguna farms were matching the yields on the IRRI farm. Farmer and experiment station yield comparisons for Nueva Ecija for the years 1970-86 (wet season) show a similar pattern. In 1970 the gap between the top third farms in Nueva Ecija and the PhilRice farm was approximately two tons. This gap diminished to less than half a ton within a decade. Since 1986 the top third farm yields have matched experiment station yields.

Over the entire time period there has been a consistent two ton yield gap between the top third farmers and the remaining two thirds for both regions. The yield gap in Laguna and Nueva Ecija is not between the farmer and the experimental potential but rather between farmers themselves. This yield gap between farmers is explained by structural differences such as land quality, access to reliable irrigation water supplies and differences in farmer ability to use the technology. There were no significant differences in varieties grown or input levels between the two groups of farmers for both sites. The highest yielding farmer group has incomes that average 40 per cent higher than the remaining farmers.

Thus over a third of the farmers in 'the rice bowl provinces' of Laguna and Nueva Ecija, have been matching the best yields on neighboring experiment stations since 1980 (Pingali *et al.*, 1997) and the overall yield gap has been narrowing. It is clear that it will be difficult to further close the yield gap.

Box 3: *Africa's emerging maize revolution?*

There is kemendous potential to increase maize production in wide areas of Africa, even with technologies on the shelf (Byerlee and Eicher, 1987). However, maize yields have stagnated despite the widespread use of improved maize varieties. At the same time, the large gaps in maize yields between research stations and farmers' fields suggest considerable unexploited potential in these areas. So far, efforts to close these gaps have met with mixed results as shown by the contrasting experiences of Ethiopia and Malawi, both land-locked and high population density countries.

In Malawi, a country where maize covers over 80% of the cropped areas and provides most calories, national maize yields were around 1 mt/ha at the same time as researchers were obtaining yields of nearly 8 mt/ha on stations. Around 1990, maize breeders developed maize hybrids that were much higher yielding than farmers' traditional varieties – and which had many of the processing and storage characteristics valued by farmers. Government programs provided fertilizer subsidies, and although many of the benefits of these subsidies went to the better-off farmers, a surprisingly large number of farmers had some experience with fertilizer. With rapid adoption of seed-fertilizer technology underway, the stage seemed set for a green revolution (Heisey and Smale, 1994).

In the early 1990s, considerable macroeconomic instability ensued and subsidies were withdrawn. Where once fertilizer use was found to be profitable under many farmers' conditions (Heisey and Smale, 1995), it was now believed to be unprofitable over wide areas of the country (Benson, 1996).

At the same time, seed delivery mechanisms were changed and adoption of hybrid seed and fertilizer has fluctuated. Only modest yield increases have been recorded and part of this yield increase can be attributed to the diffusion of improved seed, even though at this point many farmers are planting advanced generation hybrid material, instead of the first generation seed that guarantees higher yields (Smale *et al.*, 1997).

In Ethiopia, where the yield gap in maize was equally large, maize seed-fertilizer technology has been promoted by the Sasakawa Global 2000 Foundation, a non-governmental organization, through large scale demonstrations and by facilitating access to inputs through revolving credit programs. In 1998, nearly 3 million demonstrations were laid out in farmers' fields. At the same time, the government committed itself to a policy of privatizing input distribution over a period of several years aided by a World Bank project to facilitate imports and distribution of fertilizer.

The results in the 1990s have been dramatic. Although subsidies on fertilizers were phased out, the seed-fertilizer package was highly profitable in the favored areas, with farmers achieving yields of around 6 t/ha compared to the traditional 2 t/ha. Fertilizer use has tripled in three years, 25% of farmers now apply fertilizer, and food grain production has almost doubled (A. Sodhi, pers. com.). The challenge now is to complete the full transition of fertilizer importation and marketing to the private sector, and to adapt the package to less favored areas.

What these cases illustrate is the extreme importance of having adequate technology and widescale diffusion, backed by sustained institutional and infrastructural development – similar ingredients to the green revolution success in Asia.

REFERENCES

Ali, M., and Byerlee, D.: Forthcoming, 'A Decomposition Analysis of Productivity Growth and Resource Degradation in Pakistan's Punjab', Policy Research Working Paper, Rural Development Dept., World Bank, Washington, DC.

Alston, J.M., Pardey, P.G., and Roseboom, J. (1998): 'Financing Agricultural Research: International Investment Patterns and Policy Perspectives', *World Development*, 26(2), pp. 1057-1072.

Antle, J.M., and Pingali, P.L. (1994): 'Pesticides, Farmer Health and Productivity: A Philippine Case Study', *American Journal of Agricultural Economics*, August.

Blackie, M.J. (1995): 'Maize Productivity for the 21st Century: the African Challenge', in D.C. Jewell, S.R. Waddington, J.K. Ransom, and K.V. Pixley (eds.), *Maize Research for Stress Environments* (Proceedings of the Fourth Eastern and Southern Africa Regional Maize Conference, Harare, Zimbabwe, 28 March-1 April, 1994. Mexico, D.F., CIMMY), pp. xi-xxiii.

Byerlee D. (1994): 'Technology Transfer Systems for Improved Crop Management: Lessons for the Future', in J.R. Anderson (ed.), *Agricultural Technology: Policy Issues for the International community* (CAB International, Wallingford, UK).

Byerlee, D. (1992): 'Technical Change, Productivity, and Sustainability in Irrigated Wheat Systems of Asia: Emerging Issues', *Journal of International Development*, 4(5), pp. 477-496.

Byerlee, D. (1996): 'Modern Varieties, Productivity and Sustainability: Recent Experience and Emerging Challenges', *World Development*, 24(4), pp. 697-718.

Byerlee, D., and Lopez-Pereira, M. (1994): *Technical Change in Maize: A Global Perspective* (Economics Working Paper 94-02, CIMMYT, Mexico).

Byerlee, D., and Heisey, P.W. (199?): 'Past and Potential Impacts of Maize Research in Sub-Saharan Africa: A Critical Assessment', *Food Policy*, 21(3), pp. 255-77.

Byerlee, D. (1998): 'Knowledge-Intensive Crop Management Technologies: Concepts, Impacts, and Prospects in Asian Agriculture', in P. Pingali and M. Hossain (eds.), *Impacts of Rice Research* (Bangkok, Thailand, Thailand Development Research Institute, and Los Banos, the Philippines, International Rice Research Institute), pp. 113-133.

Byerlee, D., and Moya, P. (1993): *Impacts of International Wheat Breeding Research in the Developing World, 1966-90* (Mexico, D.F., CIMMYT).

Byerlee, D., Hazell, P., and Kerr, J. (1987): 'Critical Resource, Technology, and Environmental Issues for Meeting Future Grain Production Needs in Asia', *American Journal of Agricultural Economics*, 79(5), pp. 1480-84.

Byerlee, D., and White, R. (1997): 'Agricultural Systems Intensification and Diversification through Food Legumes: Technology and Policy Options' (Keynote paper to the III International Food Legumes Research Conference, 22-26 Sept., 1997, Adelaide).

Cassman, K.G., and Pingali, P.L. (1995): 'Extrapolating Trends from Long-Term Experiments to Farmers' Fields: The Case of Irrigated Rice Systems in Asia', in V. Barnett, R. Payne and R. Steiner (eds.), *Agricultural Sustainability: Economic, Environmental, and Statistical Considerations* (London, John Wiley and Sons, Ltd.).

Chand, R., and Haque, T. (1997): 'Issues Concerning Sustainability of Rice-Wheat Cropping System in the Indo-Gangetic Region', *Economic and Political Weekly* (forthcoming).

Crosson, P. (1995): 'Soil Erosion Estimates and Costs', *Science*, 269, pp. 461-63.

Duvick, D.N. (1992): 'Genetic Contributions to Advances in Yield of U.S. Maize', *Maydica*, 37, pp. 69-79.

Eicher, C.K. (1990): 'African Scientific Capacity for Agricultural Development', *Agriculture Economics*, 4, pp. 117-143.

Evenson, R.E. (1997): 'Rice Varietal Improvement and International Exchange of Germplasm', in M. Hossain and A. Siamwalla (eds.), *Impacts of 30 Years of Rice Research in Asia* (International Rice Research Institute, Los Baños, The Philippines).

Evenson, R.E., Herdt, R.W., and Hossain, M. (1996): *Rice Research in Asia: Progress and Priorities* (Wallingford, CABI in association with IRRI, Los Baños).

Fan, S., and Hazell, P. (1997): 'Should India Invest More in Less-Favored Areas?', (EPTD Discussion Paper No. 25. Washington, International Food Policy Research Institute).

Hassan, R. (ed.) (1998): *Maize Technology Development and Transfer: A GIS Application for Research Planning in Kenya* (Wallingford, U.K., CAB International in association with CIMMYT and the Kenya Agricultural Research Institute, KARI).

Hayami, Y., and Ruttan, V.W. (1975): *Agricultural Development: An International Perspective* (Johns Hopkins University Press, Baltimore).

Hayami, Y., Kikuchi, M., and Morooka, K. (1989): 'Market Price Response of World Rice Research', *Agricultural Economics*, 3, pp. 333-334.

Hazell, P., and Fan, S. (1998): 'Balancing Regional Development Priorities to Achieve Sustainable and Equitable Agricultural Growth' (Paper prepared for the AAEA International Conference on Agricultural Intensification, Economic Development and the Environment, 31 July-1 August, 1998, Salt Lake City, Utah).

Heisey, P.W., and Mwangi, W. (1997): 'Fertilizer Use and Maize Production', in D. Byerlee and C.K. Eicher (eds.), *Africa's Emerging Maize Revolution* (Boulder, Colorado, Lynne Rienner Publishers), pp. 193-211.

Heisey, P.W., and Smale, M. (1995): *Maize Technology in Malawi: A Green Revolution in the Making?* (CIMMYT Research Report No. 4. Mexico, D.F., CIMMYT).

Herdt, R.W. (1988): 'Increasing Crop Yields in Developing Countries' (Paper presented at the Annual Meetings of the American Agricultural Economics Association, 30 July-3 August 1988, Knoxville, Tennessee).

Hobbs, P., and Morris, M.L. (1996): 'Meeting South Asia's Future Food Requirements from Rice-Wheat Cropping Systems: Priority Issues Facing Researchers in the Post-Green Revolution Era', *Natural Resources Group Paper 96-01* (Mexico, D.F., International Maize and Wheat Improvement Center, CIMMYT).

Huang, J. and Rozelle, S. (1995): 'Environmental Stress and Grain Yields in China', *American Journal of Agricultural Economics*, 77, pp. 853-64.

Hussain, S.S., and Byerlee, D. (1995): 'Education and Farm Productivity in post-Green Revolution Asia', in G.H. Peters and D. Hedley (eds.), *Agricultural Competitiveness: Market Forces and Policy Choice. Proceedings of the Twenty-Second International Conference of Agricultural Economists. Harare, Zimbabwe, 22-29 August, 1994* (Aldershot, U.K., Dartmouth).

Kerr, J., Hazell, P., and Jha, D. (1998): 'Sustainable Development of Rainfed Agriculture in India' (Draft Synthesis Paper, Indian Council of Agricultural Research, New Delhi).

Khush, G.S. (1995): 'Modern Varieties - their Real Contribution to Food Supply and Equity', *Geojournal*, 35(3), pp. 275-284.

Kumwenda, J.D.T., Waddington, S.R., Snapp, S.S., Jones, R.B., and Blackie, M.J. (1997): 'Soil Fertility Management In Southern Africa', in D. Byerlee and C.K. Eicher (eds.), *Africa's Emerging Maize-based Revolution* (Boulder, Colorado, Lynne Rienner).

Lindert, P.H. (1996): 'Soil Degradation and Agricultural Change in Two Developing Countries', in *Global Agricultural Science Policy to the 21st Century* (Proceedings of an International Conference, Aug. 22-26, Melbourne).

Maredia, M.K., and Eicher, C.K. (1995): 'The Economics of Wheat Research in Developing Countries: The One Hundred Million Dollar Puzzle', *World Development*, 23(3), pp. 401-412.

McCalla, A. (1994): *Agriculture and Food Needs to 2025: Why We Should Be Concerned* (Sir John Crawford Memorial Lecture. CGIAR, World Bank, Washington, D.C.).

Morris, M., and Byerlee, D. (1998): 'Maintaining Productivity Gains in Post-Green Revolution Agriculture', in C.K. Eicher and J. Staatz (eds.), *Agricultural Development: the Third World*, third edition (Johns Hopkins Press, Baltimore, forthcoming).

Morris, M.L. (ed.) (1988): *Maize Seed Industries in Developing Countries* (Boulder, Colorado, Lynne Rienner Publishers and CIMMYT).

Pingali, P.L. (1994): 'Technological Prospects for Reversing the Declining Trend in Asia's Rice Productivity', in J.R. Anderson (ed.), *Agricultural Technology: Policy Issues for the International Community* (CAB International, Wallingford, Oxon, UK, in association with the World Bank, U.S.A.), pp. 384-401.

Pingali, P.L., and Rola, A. (1994): *Public Regulatory Roles in Developing Markets: The Case of Pesticides* (International Rice Research Institute, Los Baños, Laguna, Philippines).

Pingali, P.L., and Reeves, T.G. (1998): 'Meeting World Cereal Demand in the 21st Century', in *Proceedings of the National Agricultural and Resource Outlook Conference* (Camberra, 3-5 February 1998. P 206-213. ABARE, Canberra).

Pingali, P.L., and Heisey, P.W. (1996): 'Cereal Crop Productivity in Developing Countries: Past Trends an Future Prospects', paper presented at the conference *Global Agricultural Science Policy to the 21st Century*, Melbourne, Australia, 26-28 August.

Pingali, P.L., Hossain, M., and Gerpacio, R.V. (1997): *Asian Rice Bowls: The Returning Crisis?* (Wallingford, CABI in association with IRRI, Los Baños).

Pray, C.E., and Umali-Deininger, D. (1998): 'Private Agricultural Research: Will it Fill the Gap?', *World Development*, 26(6), pp. 1127-1148.

Pray, C.E., Mueller, R., and Ribeiro, S. (1991): 'Private Research and Public Benefit: The Private Seed Industry for Sorghum and Pearl Millet in India', *Research Policy*, 20, pp. 315-324.

Rola, A.C., and Pingali, P. (1993): *Pesticides and Rice Productivity: An Economic Assessment for the Philippines* (Los Baños, Philippines Washington, D.C., International Rice Research Institute and World Resources Institute).

Rosegrant, M.W., Leach, N., and Gerpacio, R.V. (1998): Alternative Futures for World Cereal and Meat Consumption (Washington, D.C., International Food Policy Research Institute).

Rosegrant, M.V., and Ringler, C. (1997): 'World Food Markets into the 21st Century: Environmental and Resource Constraints and Policies', *The Australian Journal of Agricultural and Resource Economics*, 41(3), pp. 401-428.

Rosegrant, M.W., and Pasandaran, E. (1990): Irrigation in Indonesia: Trends and Determinants (International Food Policy Research Institute, Washington D.C., mimeo).

Rosegrant, M.W., and Svendsen, M. (1992): 'Irrigation Investment and Management in Asia: Trends, Priorities and Policy Directions', in *Proceedings of the Planning Workshop on Projections and Policy Implications of Medium- and Long-Term Rice Supply and Demand* (Organized by International Rice Research Institute, Los Baños, Laguna, Philippines).

Ruttan, V. (1998): 'Technical Change and Agricultural Development' (Draft Chapter, Dept of Agricultural Economics, University of Minnesota, St Paul).

Sanders, J.H., Shapiro, B.I., and Ramaswamy, S. (1998): 'A Strategy for Technology Development for Semi-arid Africa', *Outlook on Agriculture*, 27(3), pp. 181-85.

Sanders, J.H., Shapiro, B.I., and Ramaswamy, S. (1996): *The Economics of Agricultural Technology in Semiarid Sub-Saharan Africa* (Baltimore, The Johns Hopkins University Press).

Seckler, D., Molden, D., and Barker, R. (1998): *Water Scarcity in the 21st Century* (International Water Management Institute, Colombo).

Smale, M. (1997): 'The Green Revolution and Wheat Genetic Diversity: Some Unfounded Assumptions', *World Development*, 25 (August 1997).

Stoorvogel, J.J., and Smaling, E.M.A. (1990): *Assessment of Soil Nutrient Depletion in Sub-Saharan Africa, 1983-2000*. Volume 1: *Main Report* (second edition) (Report 28, Winand Staring Centre for Integrated Land, Soil and Water Research, Wageningen, The Netherlands).

Traxler, G., Falk-Zepeda, J., Ortiz-Monasterio, J.I., Sayre, K. (1994): 'Production Risk and the Evolution of Varietal Technology', *American Journal of Agricultural Economics*, 76(1), pp. 1-7.

Virmani, S.S., Khush, G.S., and Pingali, P.L. (1994): 'Hybrid Rice for Tropics: Potentials, Research Priorities and Policy Issues', in R.S. Paroda and M. Rai (eds.) *Hybrid Research and Development Needs in Major Cereals in the Asia-Pacific Region* (Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific, Bangkok, Thailand), pp. 61-86.

Waibel, H. (1986): *The Economics of Integrated Pest Control in Irrigated Rice: A Study from the Philippines* (Crop Protection Monographs. Springer-Verlag, Berlin).

Wiebers, U. (1996): *Integrated Pest Management and Pesticide Management in Developing Asia* (World Bank Technical paper No. 211. Washington, D.C., World Bank).

COMPARATIVE NUTRITIVE VALUE OF VARIOUS STAPLE FOOD COMMODITIES

BIENVENIDO O. JULIANO

INTRODUCTION

Calloway (1995) observed that man, given sufficient access to food, will usually meet or exceed his energy demand, provided that the diet is not so bulky – low (<15%) in fat, high in fiber and water – that the volume needed to meet the energy requirement exceeds ingestive capacity. If a population is successful in an ecological niche, by some process of trial and error in selecting for energy, it must have found a dietary pattern that provides the minimum requirements of all the 40-45 essential nutrients (in addition to the energy sources – carbohydrates, fat, and protein): 9 or 10 amino acids, 2 fatty acids, 13 vitamins and 15-20 minerals. The amount and balance of the nutrients may not be optimal, but the requirements for population reproduction must be met.

The balancing of nutrient intake with needs is a remarkable achievement (Calloway, 1995). Success is in large part due to the fact that natural foods contain mixtures of nutrients and that, in most instances, there is no harm in eating several times as much of a nutrient as is required. Foods also supply substances that are not classified as nutrients but have beneficial properties (e.g., dietary fiber) or contain undesirable antinutritional and potentially toxic compounds (e.g., cyanide). The amount of essential nutrients required varies with age, size, sex, and reproductive status. Within these categories, individual requirements for most nutrients are normally distributed with a coefficient of variation of about 15%. Because of their metabolic functions, the quantitative requirement for some nutrients varies with the intake of others – e.g., requirements for thiamine, riboflavin and niacin are related directly to total energy intake. The bioavailability of the nutrient sometimes varies with the form the nutrient is present and the presence of interfering substances in the diet.

PRODUCTION, SUPPLY AND AVAILABILITY OF VARIOUS STAPLES

Production in 1996 of various staples by continent showed that Asia produces the most cereals, roots and tubers, dry beans, peanut, broadbean, chickpea, lentils, coconut, and plantain (FAO, 1996b; FAO, 1997) (table 1). Cereals are the major staple in the developed world, principally wheat, while rice, corn, millet and sorghum are the cereal staples in the developing world. Root crops (except for potato), banana and plantain are also consumed as staple largely in developing countries. China is the major producer of rice and sweet potato. Cassava is produced mainly in Africa, Asia and South America. Taro and yams are produced mainly in Africa but taro is produced also in Asia. Soybean is the major legume with North and Central America as the major producer. Europe is the major producer of green pea. Legumes are consumed in great quantities by vegetarians in place of meat, particularly in South Asia. More plantain is produced than banana and is produced mainly in Asia and South America, but banana is produced mainly in Africa. Banana and plantain are the key staple food in much of Uganda and parts of Tanzania (Chandler, 1995).

A comparison of diets in developed and developing countries in 1990-92 showed that developing countries had lower dietary energy, and protein and fat intakes than developed countries (FAO, 1996a) (table 2). More vegetable products were consumed in developing countries while more animal products were used in developed countries. Of the five developing-country regions, SubSaharan Africa had the lowest *per caput* energy intake, followed by South Asia. Protein and fat intakes were also lowest in these two developing-country regions.

FAO (1996a) *per caput* energy intake in developing-country regions in 1990-92 showed that cereals were the major energy source (table 2). Rice was the major dietary energy source in East and Southeast Asia and South Asia; wheat in the Near East and North Africa; corn, wheat and rice in Latin America and the Caribbean, and roots and tubers (mainly cassava), corn and sorghum and millet in SubSaharan Africa (table 2). Consumption of vegetables and fruits was least in Asia. Cereals were also the major source of carbohydrate: 73.3% in developing countries and 54.2% in developed countries in 1994 (FAO, 1998).

Cereals were the major protein source in developing countries of all regions, followed by pulses and nuts (FAO, 1996a) (table 2). SubSaharan Africa had the lowest protein intake, followed by South Asia. Vegetable oil and fat intake was lowest in East and Southeast Asia.

Table 1. *Production of Various Commodities by Continent, 1996 in 10^6 tons* (FAO, 1996b; FAO, 1997).

Commodity	World	Africa	North & Central America	South America	Asia	Europe	Oceania
Cereals, total	**2,049.6**	**127.6**	**429.4**	**94.0**	**973.1**	**390.0**	**35.5**
Rice	562.3	16.0	9.9	18.3	513.7	3.4	1.0
Wheat	584.9	22.8	96.1	21.2	242.1	178.8	23.8
Corn	576.8	44.0	263.9	48.7	156.0	63.8	0.5
Millet	29.6	12.9	0.2	0.04	15.8	0.6	0.03
Sorghum	69.0	20.9	25.8	3.5	16.7	0.6	1.6
Roots & tubers, total	**635.3**	**137.7**	**31.2**	**45.0**	**262.0**	**156.3**	**3.1**
Potato	294.8	7.8	28.2	12.1	89.2	156.2	1.4
Sweet potato	134.2	7.4	1.1	1.3	123.6	0.06	0.6
Cassava	162.9	85.0	1.0	30.6	46.1	–	0.2
Taro	5.7	3.6	0.02	0.01	1.8	–	0.3
Yam	33.1	31.7	0.5	0.4	0.2	0.001	0.3
Legumes, total[a]	**176.9**	**14.4**	**40.2**	**49.7**	**47.7**	**21.6**	**2.6**
Soybean	86.2	0.5	32.6	25.5	15.4	12.2	0.09
Beans, dry	18.6	2.2	3.3	3.5	8.8	0.8	0.04
Peanut with shell	29.2	6.2	1.8	0.7	20.4	0.02	0.05
Broadbean, dry	3.5	0.9	0.08	0.09	2.0	0.3	0.1
Chickpea, dry	8.9	0.3	0.2	0.02	8.0	0.1	0.3
Green pea, dry	10.9	0.4	1.4	0.1	1.9	6.8	0.4
Lentils	2.8	0.06	0.5	0.02	2.1	0.07	0.05
Coconut, copra	4.8	0.2	0.3	0.04	4.0	0.001	0.2
Plantain & bananas, total	**84.6**	**28.8**	**9.6**	**20.3**	**24.3**	**0.4**	**0.905**
Plantain	54.8	6.6	8.4	14.9	23.5	0.4	0.9
Banana	29.8	22.2	1.4	5.4	0.8	–	0.005

[a] Including coconut.

Table 2. *Per Caput Energy, Protein and Fat Contribution to Diets in Developed and Developing Countries and in Developing-Country Regions, 1990-92* (FAO, 1996a).

			Developing Countries					
Property	World	Developed Countries	Total	Latin America & Caribbean	SubSaharan Africa	Near East & North Africa	East & Southeast Asia	South Asia
Energy intake (kcal/d)	**2,720**	**3,350**	**2,520**	**2,740**	**2,040**	**2,960**	**2,680**	**2,290**
Contribution to energy (%)								
Vegetable products	84.3	70.9	89.7	82.6	93.4	90.4	89.1	92.6
Cereals	51.2	30.4	59.6	38.4	44.7	56.9	66.5	64.5
Rice	(22.0)			(9.4)	(7.8)	(6.2)	(40.8)	(33.7)
Wheat	(19.5)			(13.2)	(5.4)	(42.8)	(17.1)	(21.0)
Corn	(6.1)			(15.3)	(14.7)	(4.7)	(6.8)	(2.8)
Sorghum & millets	(2.6)			(0.1)	(14.6)	(0.8)	(0.9)	(6.6)
Pulses & nuts	4.0	2.3	4.7	4.8	7.2	4.0	3.4	6.3
Roots & tubers	5.0	3.8	5.4	4.1	21.0	2.2	5.1	1.6
Cassava	(1.6)	(2.2)	(14.9)	(0.0)	(0.9)	(0.5)		
Vegetables & fruits	4.3	4.9	4.8	5.2	5.6	7.0	3.3	3.0
Vegetable oils & fats	8.2	11.1	7.0	11.1	8.0	10.6	5.1	6.8
Protein intake (g/d)	**71**	**102**	**62**	**68**	**49**	**80**	**65**	**55**
Contribution to protein (%)								
Vegetable products	64.5	42.3	75.8	57.1	79.2	77.4	75.8	82.6
Cereals	47.2	29.0	56.2	38.1	48.2	60.8	59.1	62.3
Pulses & nuts	8.3	3.9	10.5	10.8	16.8	7.6	8.2	13.2
Roots & tubers	2.7	2.9	2.5	2.6	7.9	1.6	2.4	1.1
Vegetables & fruits	4.8	4.5	5.0	3.9	4.4	6.4	5.5	4.3
Fat intake (g/d)	**69**	**125**	**51**	**78**	**41**	**70**	**51**	**41**
Vegetable products fat	37	52	32	44	32	50	27	30

Gross Composition of Plant Staples

Food composition tables give differing values for nutrient levels of the food staples. A comparison of the gross composition of cereals, legumes (pulses), coconut, roots, tubers, bananas and plantain (Souci *et al.*, 1986; FAO, 1998; USDA, 1998) (tables 3-5) showed that, in general, legumes have higher energy contents than cereals, due to their higher fat content, particularly soybean, peanut and coconut. Roots, tubers, bananas and plantain have the lowest energy content and nutrient level, due to their high moisture content; this also contributes to these foods' shorter shelflife. Legumes (dicots) have the highest protein content, followed by cereals (monocots) and then by roots, tubers, plantain and bananas.

Legumes tend to be richer in crude ash, total and soluble dietary fiber, and total sugars and galactose-containing sugars (raffinose, stachyose and verbascose) but lower in available carbohydrates (carbohydrate by difference – insoluble dietary fiber) and starch (tables 3 and 4). Starch level is low in fat-rich legumes (0-6.3%) and in broadbean (24.4%). Cereals and legumes have higher phytic acid and tannin contents than roots, tubers and fruits (tables 3-5). Pigmented seeds, including cereals, are rich in tannins. Among cereals, tannin content is highest in sorghum and lowest for unpigmented brown rice.

Table 3. *Nutritional Value of Major Cereals/100 Grams Edible Portion* (Souci *et al.*, 1986; FAO, 1998; USDA, 1998).

Cereal	Energy (kJ)	Moisture (g)	Protein (g)	Fat (g)	Crude ash (g)	Dietary fiber[a] (g)	Carbohydrate[b] (g)	Starch (g)	Sugars[c] (g)	Phytic acid (g)	Tannin (g)
Brown rice	1,490	14.0	7.3	2.2	1.4	3.3(1.3)	71.1	69.1	1.9(0.2)	0.9	0.01(0.6)[d]
Wheat	1,360	14.0	10.6	1.9	1.4	10.5(2.7)	61.6	61.8	2.1(0.4)	1.0	0.4
Corn	1,460	14.0	9.8	4.9	1.4	9.0(1.3)	60.9	59.3	1.6(0.2)	0.9	0.4
Barley	1,410	14.0	9.3	2.8	1.7	16.4(1.7)	53.4	51.4	2.0(0.2)	1.1	0.6
Sorghum	1,340	14.0	8.3	3.9	2.6	13.8(2.7)	57.4	50	4(0.3)	1.0	1.6
Millet	1,490	14.0	11.5	4.7	1.5	8.0(2.3)	64.6	60	1.3(0.7)	0.5	0.6
Rye	1,350	14.0	8.7	1.5	1.8	13.1(4.7)	60.9	57.9	2.0(0.3)	1.0	1.1
Oats	1,520	14.0	9.3	5.9	2.3	9.9(1.7)	63.0	63.0	1.3(0.3)	0.9	0.8
Triticale	1,350	14.0	11.2	1.3	1.4	10.8(1.8)	60.9	56.3	2.2(0.6)	1.0	0.7
Mean	**1,420**	**14.0**	**9.6**	**3.2**	**1.7**	**10.5(2.2)**	**61.5**	**58.8**	**2.0(0.4)**	**0.9**	**0.9**

[a] Soluble dietary fiber in parentheses. [b] Available, by difference. [c] Raffinose + stachyose + verbascose in parentheses.
[d] Black rice value in parenthesis.

Table 4. *Nutritional Value of Whole-Grain Legumes/100 Grams Edible Portion* (So *al.*, 1986; FAO, 1998; USDA, 1998; Salunkhe and Kadam, 1989; Deshpande and D daran, 1990; Holland *et al.*, 1991).

Legume	Energy (kJ)	Moisture (g)	Protein (g)	Fat (g)	Crude ash (g)	Dietary fiber[a] (g)	Carbohydrate[b] (g)	Starch (g)	Sugars[c] (g)	Phytic acid (g)	Ta
Soybean	1,740	8.5	35.9	18.6	4.7	9.3(7.7)	15.8	4.8	5.5(4.8)	1.2	
Mung beau	1,440	10.0	24.0	1.1	3.5	10.0(2.4)	46.5	45.3	7.5(6.4)	0.7	
Peanut	2,340	6.3	25.6	46.1	2.2	8.0(2.8)	12.5	6.3	6.2(1.4)	0.9	
Broadbean	1,430	11.0	26.1	2.1	3.0	19.0(3.1)	32.5	24.4	5.9(5.0)	1.6	
Kidney bean	1,410	12.1	20.3	1.2	3.6	10.7(5.9)	57.9	46.2	6.7(5.1)	0.8	
Chickpea	1,510	10.0	21.3	5.4	2.7	10.7(5.6)	51.1	43.8	2.6(2.6)	0.65	
Green peas	1,290	13.3	21.6	2.4	2.7	16.6(5.1)	43.4	47.6	5.3(2.8)	1.2	0.4
Lentils, green	1,410	10.8	24.3	1.9	2.1	8.9(5.1)	48.8	44.5	2.0(2.0)	0.6	
Lentils, red	1,450	11.1	23.8	1.3	2.1	10.8(3.1)	56.3	50.8	2.4(2.0)	0.6	
Coconut, dried	2,260	14.3	4.8	46.6	1.5	12.5(6.5)	26.7	0	5.6		
Mean	**1,810**	**10.7**	**22.8**	**12.7**	**2.8**	**12.9(4.7)**	**39.2**	**31.4**	**5.0(3.6)**	**0.9**	

[a] Soluble dietary fiber in parentheses. [b] Available, by difference. [c] Raffinose + stachyose + verbascose in parentheses.

Table 5. *Nutritional Value of Starchy Roots, Tubers, Plantain and Banana/100 G Edible Portion* (Souci *et al.*, 1986; Bradbury and Halloway, 1988; FAO, 1998; U 1998).

Root	Energy (kJ)	Moisture (g)	Protein (g)	Fat (g)	Crude ash (g)	Dietary fiber[a] (g)	Carbohydrate[b] (g)	Starch (g)	Sugars[c] (g)	Phytic acid (g)	Ta
Potato	318	79.0	2.1	0.2	1.0	1.3(0.6)	17.2	16.6	0.6	0.1	
Sweet potato	438	71.1	1.4	0.2	0.7	1.6(0.4)	25.7	20.1	2.4(0.5)	0.05	
Cassava	580	62.4	0.5	0.2	0.8	1.0(0.6)	34.2	31.0	0.8	0.05	0
Yam	406	74.2	2.1	0.1	0.8	1.3(0.7)	21.6	19.3	0.6(0.03)	0.06	
Taro (cocoyam)	480	69.1	1.1	0.1	0.9	2.9(2.4)	27.3	24.5	1.0(0.03)	0.08	
Plantain	476	68.2	0.9	0.2	1.0	1.5(0.7)	29.3	22.9	6.2	0.1	0.03
Banana	403	75.1	1.2	0.3	0.8	1.6(1.1)	23.2	2.3	20.9	0.07	
Mean	**429**	**71.3**	**1.3**	**0.2**	**0.9**	**1.6(0.9)**	**25.5**	**19.5**	**4.6(0.2)**	**0.07**	

[a] Soluble fiber in parentheses. [b] Available, by difference. [c] Raffinose + stachyose + verbascose in parentheses.

PROTEIN QUALITY OF STAPLES: AMINO ACID SCORE AND N BALANCE

Storage proteins (protein bodies [PBs]) in legumes (dicots) are salt-soluble proteins (globulin), but those in cereals (monocots) are alcohol-soluble protein (prolamin)-rich PBs, together with alkali-soluble protein (glutelin) matrix. Only rice has, in addition, glutelin-rich crystalline, segmented PB type II (Bechtel and Juliano, 1980).

Rat Balance Data

Nitrogen balance data in five growing rats measure true digestibility (TD, % digestion of ingested N), biological value (BV, % retention of absorbed N), and net protein utilization (NPU, % retention of ingested N), corrected for endogenous fecal and urine N losses (Eggum, 1973). Separate measurement of TD and BV permits knowing the cause of differences in NPU (TD x BV/100) among proteins. Utilizable protein is calculated from NPU x protein content. NPU may underestimate protein quality because of the higher amino acid requirement of the rat relative to man. Balance studies in growing rats at the Danish Institute of Animal Science showed that among the raw cereals, brown (dehulled) rice had the highest digestible protein and energy values and NPU (table 6). Digestible energy and protein balance values were low in some cereals due to high fiber content and tannin. Boiling cereals for 30 min reduced the TD mainly of rice, the residual fecal protein particles representing the core of prolamin-rich PB I (Resurreccion *et al.*, 1993). Cooking also reduces TD and increases BV of sorghum protein (Eggum *et al.*, 1983b).

Digestible energy and TD, BV and NPU of legumes overlapped with those of cereals (tables 6 and 7). But utilizable protein levels of legumes are higher than those of cereals because of higher protein content.

Fewer balance data are available on roots, tubers and fruits (table 7), probably because of their low protein content (table 5). Boiled potato has an NPU of 62-67%, reflecting its good amino acid pattern (table 7). Sweet potato had an NPU similar to that of potato (Tsou and Hong, 1989). But protein efficiency ratio (PER) in growing rats (with the corn check PER as 2.50), was cassava 2.21, white yam 2.25, yellow yam 2.66, cocoyam (taro) 2.79, and plantain 2.38 (Omole *et al.*, 1978).

Legume protein is deficient in sulfur-containing amino acids, cystine and methionine but has excess lysine (table 8), based on the FAO/WHO/UNU (WHO, 1985) amino acid pattern for preschool children. However, peanut and coconut proteins are atypical, being limiting in lysine. By contrast, cereal protein is deficient in lysine, but has excess sulfur amino acids,

Table 6. *Balance Data in Growing Rats of Raw and Cooked Whole-Grain Cereals. Danish Institute of Animal Science* (Eggum, 1973; Heger and Eggum, 1991).

Food	True N digestibility (%)	Biological value (%)	Net Protein Utilization (%)	Utilizable protein[a] (%)	Digestible energy (% of total)
Raw cereal					
Rice, brown	100	74	74	5.4	96
Wheat	97	55	53	5.6	86
Corn	95	61	58	5.7	81
Millet	93	60	56	6.4	87
Sorghum	85	59	50	4.2	80
Rye	77	78	59	5.1	85
Oats	84	70	59	5.5	70
Barley	88	70	62	7.9	79
Triticale	89	65	58	6.5	86
Mean	**90**	**66**	**59**	**5.8**	**83**
Cereal, boiled 30 min					
Rice, milled	89	78	69	6.2	95
Wheat	93	66	64	6.7	
Corn	94	61	58	5.7	
Sorghum	88	48	42	3.6	
Rye	78	79	62	5.3	
Oats	94	79	74	6.9	
Barley	85	72	61	7.8	
Mean	**89**	**69**	**61**	**6.0**	

[a] NPU x crude protein/100.

which explains why a cereal-legume diet has better amino acid balance or score than either cereal or legume alone (Eggum *et al.*, 1987). Tuber, root, plantain and banana proteins are also deficient in lysine. Amino acid score is the percentage adequacy of the first or most limiting amino acid in the food relative to the FAO/WHO/UNU (WHO, 1985) amino acid requirements of the preschool child (table 8). Young *et al.* (1989) reported higher lysine requirements for adults from carbon balance studies.

Protein quality has been measured based on amino acid score using the FAO/WHO/UNU (WHO, 1985) preschool child amino acid pattern of

Table 7. *Balance Data in Growing Rats of Raw and Cooked/Processed Legumes and Root Crops. Danish Institute of Animal Science* (Beames and Eggum, 1981; Eggum, 1969; Eggum *et al.*, 1989; Eppendorfer *et al.*, 1979; Tsou and Hong, 1989).

Food	True N digestibility (%)	Biological value (%)	Net Protein Utilization (%)	Utilizable protein[a] (%)	Digestible energy (% of total)
Raw legume					
Soybean meal	91	62	56	29	
Peanut meal	92	60	56	30	
Brown bean	72	89	64	7.2	62
Broadbean[b]	91	50	45	13	
Coconut meal	78	72	56	12	
Mean	**85**	**67**	**55**	**18**	
Cooked/processed legume					
Soy protein isolate	92	62	57		80
Peanut butter	92	67	61		
Kidneybean	73	63	46	11	76
Chickpea	88	63	56	12	87
Pea protein	94	62	58	31	85
Mean	**88**	**63**	**56**	**18**	**82**
Potato, boiled	83	81	67	1.0	
Potato, boiled	89	70	62	1.5	
Sweet potato, raw	80	82	66	1.0	
Sweet potato, cooked	88	77	68	1.0	
Mean	**85**	**78**	**66**	**1.1**	

[a] NPU x crude protein/100. [b] Raw: autoclaved 1:1.

essential amino acids as standard. Recently amino acid score has been corrected for differences in protein digestibility (TD) by multiplying the score with TD (FAO, 1991). Amino acid score x TD values in table 8 tended to be lower than NPU in cereals and peanut, similar in sweet potato and coconut, but tended to be higher than NPU in most legumes (tables 6 and 7). While this has improved the protein quality values, the method assumes that protein amino acid digestion is fairly random, which is not the case in some proteins, particularly cooked rice protein (Eggum *et al.*, 1993a; Eggum *et al.*, 1993c). Cooking rice reduces TD from 100% to 85-90%, but

Table 8. *Essential Amino Acid Content and Amino Acid Scores of Whole-Grain Cereals and Legumes, Roots, Tubers, Plantain and Bananas* (USDA, 1998; Eggum, 1969; Eggum, 1973; Eggum *et al.*, 1989; Eppendorfer *et al.*, 1979; Heger and Eggum, 1991; USDA, 1998).

Food	Protein content (%)	Lysine	Threonine	Cystine + methionine	Tryptophan	Amino acid score[a] (%)	Amino acid score X TD[b](%)
		(g / 16 g N)					
WHO (1985) pattern		5.8	3.4	2.5	1.1	100	100
Rice, brown	6.9	3.8	3.6	3.9	1.1	66lys	66
Wheat	10.9	2.3	2.8	3.6	1.0	40lys	38
Corn	8.6	2.5	3.3	3.9	0.6	43lys	41
Millet	11.4	2.7	3.2	3.6	1.3	47lys	44
Sorghum	11.2	2.7	3.3	2.8	1.0	47lys	40
Rye	8.8	3.7	3.3	3.7	1.0	64lys	49
Oats	10.1	4.0	3.6	4.8	0.9	69lys	58
Barley	8.8	3.2	2.9	3.9	1.1	55lys	48
Triticale	11.2	3.2	3.0	4.1	1.6	55lys	49
Mean	**9.8**	**3.1**	**3.2**	**3.8**	**1.1**	**54lys**	**48**
Soybean meal	46.2	6.0	3.7	3.2	1.3	100	94
Soy protein isolate	88.2	6.0	3.8	2.5	1.1	100	95
Peanut meal	49.5	3.2	2.7	2.2	1.0	55lys	51
Peanut butter	50	3.0	2.4	2.1	0.9	52lys	48
Brown bean	22.5	6.8	4.5	2.3	1.3	92c+m	67
Broadbean	28.0	6.3	3.6	2.3	0.9	82trp	74
Kidney bean, canned	23.6	6.8	4.1	2.0	1.0	80c+m	58
Chickpeas, canned	21.2	6.6	3.5	2.9	0.9	81trp	71
Pea protein	53.1	6.9	3.4	2.4	1.1	96c+m	90
Coconut meal	20.9	4.2	3.5	3.7	1.1	72lys	56
Mean	**40.3**	**5.6**	**3.5**	**2.6**	**1.1**	**81**	**70**
Potato, boiled	1.5	6.3	4.1	3.6	1.1	100	83
Potato, boiled	2.4	5.3	3.6	2.8	1.1	91lys	81
Sweet potato	1.4	4.7	4.7	3.1	1.2	81lys	65
Cassava	1.4	3.1	2.0	2.7	1.3	53lys	
Yam	1.6	3.7	3.4	2.5	0.8	64lys	
Taro	1.1	4.2	4.4	3.3	1.5	72lys	
Banana	1.1	4.4	3.1	2.6	1.1	76lys	
Plantain	1.4	4.4	2.5	2.7	1.1	76lys	
Mean	**1.5**	**4.5**	**3.5**	**2.9**	**1.2**	**77lys**	**76**

[a] First limiting amino acid: lys = lysine, c+m = cystine + methionine, trp = tryptophan.

[b] True digestibility data from tables 6 and 7.

Table 9. *Comparative Protein Utilization of High-Protein and High-Lysine or Cystine + Methionine Mutant Cereals, Soybean and Potato in Growing Rats. Danish Institute of Animal Science* (Eggum, 1969; Eggum and Juliano, 1973; Eggum *et al.*, 1983a, 1995; Eppendorfer *et al.*, 1979).

Cereal sample	Protein (%)	Lysine or cys + met (g/16gN)	True digestibility (%)	Biological value (%)	Net Protein Utilization (%)	Amino acid score X TD (%)
Corn, normal	9.6	3.0	96	61	58	50
Corn, *opaque-2*[a]	9.4	4.1	97	78	75	68
Barley, normal	12.9	3.3	87	78	68	50
Barley, Lysimax	13.8	4.7	84	89	75	68
Barley, 609	14.2	4.3	86	88	75	63
Rice, milled	6.0	4.1	100	75	75	71
Rice, milled	11.2	3.4	100	67	67	59
Wheat		3.2	94	62	58	52
Wheat, high protein		2.6	90	59	53	40
Sorghum		2.4	85	70	60	35
Sorghum, high protein		1.8	92	52	48	28
Soybean meal		(3.4)[b]	91	72	65	91
Soybean meal		(2.3)[b]	94	52	49	86
Potato, boiled	1.6	6.3	83	81	67	90
Potato, boiled	2.6	5.3	89	70	62	82
Potato, boiled	4.3	4.2	91	59	54	66

[a] Mean of four samples. [b] Cystine + methionine values in parentheses.

amino acid digestibility data showed less effect on lysine than on sulfur amino acids (Eggum *et al.*, 1977). The NPU of cooked rice also is not affected by cooking, since BV increases correspondingly. Thus TD measurement is preferably done on raw rice in rice and rice diets (Eggum *et al.*, 1993c) to avoid underestimating protein quality.

Considerable variation in protein content and lysine and cystine-methionine contents of protein occur in food commodities due to genetic and environmental factors and this affects TD, BV and NPU of the protein in rats (table 9). Within samples of the same food, the higher protein content reduces NPU whereas the better amino acid balance (lysine in cereals

Table 10. *Protein, Lysine, Cystine + Methionine, Free Sugars and Tannin Conten* *Balance Data in Growing Rats of Boiled Milled Rice and Milled Rice-Whole L* *Diets. Danish Institute of Animal Science-International Rice Research Institute* (E *et al.*, 1987).

Boiled diet[a]	Protein (%)	Lysine	Cys+ met	Free sugars (%)	Tannins (%)	Digestible energy (%)	TD (%)	BV (%)	NPU (%)	Utilizable protein (%)
		(g/16g N)								
Milled rice	12.7	3.5	4.4	0.2	0.00	92	86	73	63	8.0
Rice-bush sitao green	14.4	4.6	3.8	4.1	0.8	88	81	80	65	9.4
Rice-bush sitao green	16.0	4.3	3.7	3.1	0.5	89	83	78	65	10.4
Rice-cowpea black	14.9	4.7	3.8	2.1	0.2	90	86	78	67	10.0
Rice-cowpea beige	15.1	4.7	3.8	1.8	0.01	91	90	72	65	9.8
Rice-mungbean green	14.9	4.8	3.6	1.7	0.08	92	88	79	70	10.4
Rice mungbean yellow	15.4	4.8	3.6	1.6	0.07	90	86	73	63	9.7
Rice-peanut brown 1	14.6	3.6	3.9	1.4	0.08	90	90	72	65	9.5
Rice-peanut brown 2	15.7	3.7	3.9	1.9	0.1	92	90	76	68	10.7
Rice-pigeon pea brown	14.3	4.2	3.7	2.5	0.2	86	80	79	63	9.1
Rice-pigeon pea gray	14.7	4.1	3.8	2.2	0.02	88	85	79	67	10.0
Rice-soybean beige 1	16.0	4.1	3.9	1.7	0.00	91	89	79	70	11.3
Rice-soybean beige 2	16.0	3.8	4.0	1.3	0.01	91	89	79	70	11.2
Rice-legume mean	**15.2**	**4.3**	**3.8**	**2.1**	**0.2**	**90**	**86**	**77**	**66**	**10.1**
Pooled standard deviation		±0.3	±0.2	±0.04	±0.05	±0.7	±0.8	±0.8	±0.9	±0.1
Coefficient of variation (%)						0.8	0.9	1.0	1.5	1.5

[a] Milled rice-whole legume diets (2:1 N basis). Color after legume name refers to pericarp color.

and cystine-methionine in legumes) improves NPU. But the increase in protein content still results in an increase in utilizable protein content of most foods. Amino acid score x TD showed the same trend as NPU, but was lower than NPU in cereals and higher than NPU in soybean and potato.

While balance studies on single protein sources have academic value, balance studies on mixed diets simulating actual diets have practical value. Cooked rice-whole legume diets (2:1 N basis) demonstrated improved amino acid score X TD in all diets over boiled high-protein rice, but some had higher free sugars (1.4-4.1% vs. 0.2%) and tannins (0-0.8% vs. 0%) (Eggum *et al.*, 1987) (table 10). Some of the diets had comparable digestible energy and higher NPU than rice alone, such as rice-soybean. Amino acid score x TD was lower than NPU in milled rice but no trend was shown in rice-legume diets.

Human Balance Data

Comparative human balance data on preschool children are limited. The most exhaustive studies were at the Instituto de Investigacion Nutricional (Lima, Peru) in collaboration with the Johns Hopkins University (table 11). Oat and rice and *opaque-2* corn had the highest apparent N retention among the cereals tested. Sorghum had the lowest digestibility. Sorghum and degermed corn had the lowest apparent N retention, while oat and whole quality protein corn had the highest. Protein quality based on casein was highest for oat and lowest for sorghum. Increased protein content decreased protein quality in rice but not in wheat, probably because lysine content still decreased in rice with increase in protein content, but this was not so in wheat in the protein content range involved. Whole corn has better protein quality than degermed corn, and the high lysine *opaque-2* mutation improved protein quality particularly in degermed corn.

Soy protein isolate and peeled potato proteins had the same protein quality as that of rice (table 11). Brown/black beans had poor N retention although absorption was comparable with that of potato. Even in a 75% cassava diet, only 13% of the protein is contributed by cassava (Morales and Graham, 1987).

Protein requirements (WHO, 1985) are based on good quality protein such as egg and milk, and more of the poorer quality protein are required to compensate for the lower protein quality. Protein and amino acid requirements are higher in preschool children than in adults (table 12). Using developing-country weaning diets as part of the FAO/WHO/UNU program on energy and protein requirements, rice-fish, rice-mung bean and corn-black bean weaning diets were shown to have comparable apparent retention and absorption in preschool children as rice-milk diet (80% and 30%) (table 12). The safe levels of daily protein requirements of 1.09-1.70 g/kg body weight were close to FAO/WHO/UNU data. Sulfur amino acids were adequate but lysine was close to the WHO requirement of 5.8%. The Filipino diets contained banana and sweet potato and the Thai diet contained banana: protein contribution to the rice-whole mungbean diet (Intengan *et al.*, 1984) was 10% from banana and 9% from sweet potato.

Because adults have lower protein and essential amino acid requirements than growing children (WHO, 1985), most developing-country diets, including cassava- and plantain-based diets, supply these protein require-

Table 11. *Comparative Protein Utilization and Fecal Dry Weight for Peruvian Pres Children Fed Cooked Cereals, Legumes and Tubers. Instituto de Investigacion Nutrici Johns Hopkins University* (Graham, 1971; Graham *et al.*, 1979; Graham *et al.*, Graham *et al.*, 1989; Graham *et al.*, 1990; Lopez de Romaña *et al.*, 1980; MacLean 1976; MacLean *et al.*, 1978; MacLean *et al.*, 1979; MacLean *et al.*, 1981).

Cooked food	Protein content (%)	Lysine (g/16 g N)	No. of children	Daily N intake (mg/100 kcal)	Apparent nitrogen absorption (%)	Apparent nitrogen retention (%)	Protein quality (% of casein)	Utilizable protein (%)	Fe dry we (g/
Milled rice	7.2	3.9	8	240	67 ± 9	29 ± 9	76	5.5	16
Milled rice	11.4	3.4	8	240	65 ± 5	23 ± 2	61	7.0	10
Wheat noodles	11.4	<2.5	9	262	81 ± 3	20 ± 6	51	5.8	13
Wheat, whole	13.0	2.7	4	260	75 ± 4	20 ± 4	45	5.9	54
Wheat, whole HP	16.9	2.6	4	260	79 ± 2	29 ± 6	63	10.7	42
Wheat, whole HP	17.7	2.8	4	260	76 ± 3	28 ± 6	62	11.0	52
Whole corn meal (normal)	8.3	2.9	6	256	73 ± 2	23 ± 6	68	5.6	29
Whole corn meal (opaque-2)	8.6	3.4	6	256	71 ± 4	30 ± 8	76	6.5	31
Degermed corn meal (normal)	7.1	2.2	6	256	64 ±11	15 ± 9	41	2.9	29
Degermed corn meal (opaque-2)	6.5	3.4	6	256	70 ± 6	23 ± 6	62	4.0	31
Whole corn meal	8.2	2.6	6	297	69 ± 7	22 ±10	54	4.4	34
Whole corn meal (quality protein)	10.2	3.9	6	300	70 ± 5	32 ± 4	78	7.9	29
Whole sorghum (normal)	12.0	2.2	9	320	46 ±21	12 ± 1	28	3.4	38
Whole sorghum (high lysine)	12.4	3.0	7	320	54 ±15	16 ±10	37	4.6	35
Oat flour	14.0	(4.0)	9	357	74 ± 8	33 ±11	92	12.9	27
Mean	**11.0**	**3.0**	**7**	**276**	**69 ± 7**	**24 ± 7**	**60**	**6.5**	**31**
Soy milk			3	251		18			
Soy protein			4	259		17	59		
Soy protein[a]			10	240	78 ± 5	40 ±15	75		
Soy protein[b]			7	240	86 ± 3	26 ±10	71		
Brown/black beans, precooked	24.0		7	258	66 ± 6	10 ± 6	31	7.5	123
Mean			**6**	**250**	**77 ± 5**	**22 ±10**	**59**		
Peeled potato	5.8	6	7	201	66 ± 4	34 ± 6	77	4.5	30

[a] Torún *et al.* (1981) with Guatemalan children. [b] Egaña *et al.* (1984) with Chilean children.

Table 12. *Comparative Apparent Nitrogen Balance of Weaning Foods in Preschool Children in Developing Countries.*

Property	Rice-fish[a] (66:34)	(71:20)	(7:3)	Rice-whole mung bean (38:33)	Rice-hulled mung bean (51:49)	Rice-milk (1:1)	Corn tamale-black bean (58:42)	Mean
Children (no./source)	7 Fil	12 Fil	6 Thai	5/6 Fil	5/8 Fil	5/8 Fil	5 Guatemalan	7
Children's age (yr)	1.9/2.1	1.8	0.8	2.2/2.1	1.8/2.1	1.8/2.1	1.5	1.7
Energy (kcal/kg/day)	110	100	100	100	100	100	100	101
N intake (mg/kg/day)	240	187	276	240	235	196	277	236
Lysine (g/16 g N)	6.7	5.4		5.2	5.4/4.7	5.9/5.4		5.6
Cys + met (g/16 g N)	4.3	3.7		3.5	4.1/3.5	5.1/3.7		3.9
Apparent N retention (%)	67±3	73	62±4	62±7	76, 58±6	80, 67±5	56±7	66±5
Apparent N absorption (%)	30±6	28	26±3	28±7	23	30	23±4	27±5
Apparent energy absorption (%)			93±1		90±2	92±2	91±8	92±3
True N digestibility (% of intake)			69±4		70±6	80±5	66±9	71±6
Biological value (%)			71±3					
NPU (%)			49±3					
Protein requirement PRm (g/kg/day)	0.70±0.15, 0.87±0.15[c]			1.00±0.20, 1.14±0.21[c]	1.02±0.16[c]	0.81±0.15[c]		0.92±0.17
Safe $PR_{0.975}$	1.00, 1.18[c]		1.7	1.39, 1.56[c]	1.34[c]	1.11[c]	1.65	1.39
Reference[b]	1,2	3	4	1,5	1,6	1,6	7	

[a] Spanish mackerel, surgeon fish and fresh-water fish, respectively.

[b] References: 1. Cabrera-Santiago *et al.* (1986). 2. Intengan *et al.* (1981). 3. Roxas *et al.* (1975). 4. Tontisirin *et al.* (1984). 5. Intengan *al.* (1984). 6. Roxas *et al.* (1976). 7. Torún and Viteri (1981).

[c] Allowing 15 mg/kg body wt/day for growth in addition to 10 mg N/kg/day for miscellaneous integumental loss.

ments adequately based on the multilevel slope-ratio technique, except for pregnant and lactating women who need more protein for the fetus and for milk production (table 13). Only the Nigeria and Taiwan (China) sweet potato data were based on a single N level and tended to underestimate protein requirements. Meat and meat products have high amino acid scores (FAO, 1992) and improve protein quality of diets in developing countries.

Table 13. *Protein Requirements, Nitrogen Balance in Adult Man and Limiting A Acids in Practical Low-Cost Diets* (WHO, 1985).

Country & Diet	Age(yr.) /(no.) of men	Energy level (kcal/ kg/d)	Protein Requirement[a] (g/kg/day)		TD (%)	BV (%)	NPU (%)	Lys	Cys+ met
			Intercept	Safe level				(g/16 g N)	
Requirement pattern									
Preschool child	2- 5	100	0.86-0.91	1.06-1.13				5.8	2.5
School children	10-12	50	0.79-0.81	0.98-1.00				4.4	2.2
Adult	19-65	40	0.60	0.75				1.6	1.9
Brazil rice-bean	22(8)	46	0.70±0.10	0.89	80±6	44	33	5.6	3.0
China rice mixed	38(10)	45	0.99±0.12	1.23	89	51	45		
Taiwan, China rice	24(15)	42	0.80±0.19	1.18	96±3	45±11	43±12		
Taiwan, China 90% sweetpotato	19(5)	54	0.60±0.04	0.68	81±6	78±6	63±6	3.7	3.5
Philippines rice-fish	28(7)	58	0.64	1.12	90±2	40±3	36±2	6.8	3.7
Thailand rice-fish	21(12)	45	0.77±0.11	1.23	80±5	25±10	21±7		
India wheat-rice-legume	25-39(12)	43	0.54±0.05	0.64				4.9	3.4
Chile wheat-potato-rice-bean	24(8)	49	0.82±0.09	1.00	88	46	42		
Turkey mixed	22(15)	51	0.65±0.11	0.79	94	65	60		
Mexico corn-bean-wheat	22(8)	41	0.70±0.07	0.85	92	56	52	3.9	3.3
Colombia cassava-meat	22(11)		0.71±0.02	0.75	100	48	48		
Colombia rice-bean	24(8)		0.80±0.04	0.88	86	52	45		
Guatemala corn-bean	23-35(5)	45-50	0.67±0.09	0.85	77			4.9	3.0
Guatemala rice-bean	23-35(10)	45-50	0.66±0.09	0.84	79			5.0	3.2
Guatemala plantain-bean	23-35(10)	45-50	0.77±0.23	1.23	70			6.1	2.4
Nigeria rice diet	27(18)	43	0.55±0.13	0.81	89±2	80±15	71±10	4.5	3.1
Nigeria cassava diet 1	27(6)	42	0.55±0.08	0.71	89±3	66±7	59±7	4.2	2.4
Nigeria cassava diet 2	27(6)	41	0.55±0.11	0.77	95±3	72±7	68±7	6.3	3.4
Nigeria sorghum diet	27(6)	44	0.55±0.20	0.95	79±3	74±7	58±7	3.9	3.2
Japan soy protein-fish	22(8)	45	0.73±0.09	0.91	99	51	51±12	2.2	
Mean	**26**	**46**	**0.69±0.10**	**0.92**	**87±4**	**56±8**	**50±8**	**4.8**	**3.1**

[a] Recalculated with 8 mg N/kg/day for miscellaneous losses. Safe level (P = 0.975) = PR + 2SD. Based on multiple level N b regression line, except single level for Taiwan, (China) sweet potato and Nigeria diets.

[b] References: 1. Dutra de Oliveira and Vannucchi (1984). 2. Chen *et al.* (1984). 3. Huang and Lin (1982). 4. Huang *et al.* (5. Intengan *et al.* (1982). 6. Tontisirin *et al.* (1981). 7. Agarwal *et al.* (1984). 8. Yanez *et al.* (1984). 9. Ozalp *et al.* (1984). 10. B and Lopez-Castro (1981). 11. Fajardo *et al.* (1981). 12. Bressani *et al.* (1981). 13. Nicol and Phillips (1978). 14. Inoue *et al.* (19

CARBOHYDRATES: GLYCEMIC INDEX, RESISTANT STARCH AND DIETARY FIBER

Carbohydrates are the single most important source of food energy in the world, comprising some 40-80% of total food intake (FAO, 1998). Starch is the major food polysaccharide. Starch occurs in microcrystalline granules of either A and B type and consists of a branched fraction (amylopectin) and a linear fraction (amylose). Amylose content of starch is highest for legumes, then cereals, and root crops (table 14). Amylose in cereal and legume starch (but not in root starch) has bound lipids.

Glycemic index measures the increase in fasting plasma glucose level within 3 hr of consuming 50 g available carbohydrates with either glucose or white bread as 100% (Jenkins *et al.*, 1981). Glycemic index based on glucose are usually lower than glycemic index based on white bread (table 14). Legumes have lower glycemic index than cereals and roots and tubers. Glycemic index decreases with increase in amylose content of starch: it is highest for waxy (0-2% amylose) starch and lowest in legumes with about 35% amylose. In rice, waxy (0-2% amylose) and low-amylose (12-20%) rices with low starch gelatinization temperature (GT <70°C) have higher glycemic index than intermediate- (20-25%) and high-amylose rices with intermediate GT (Goddard *et al.*, 1984; Juliano and Goddard, 1986). Among high-amylose rices differing in GT cooked in optimum cooking water (68-69% water), low-GT rice had higher glycemic index (91-94%) than intermediate-GT rice (62-71%) (Panlasigui *et al.*, 1991), but the low-GT rice gave the same glycemic index as the others (75-81%) when all were cooked to minimum cooking time (14-20 min) in excess water (69-70% water). Bangladeshi raw and parboiled rices cooked in excess water have glycemic index and *in vitro* starch digestibility that correlated negatively with amylose content but not with GT (Larsen *et al.*, 1996; Tetens *et al.*, 1997). Resistant starch in cooked rice in rats also was higher in intermediate-GT rice (1.5-3.6%) than low-GT rice (0.1-0.5%) for rices with intermediate and high amylose (Eggum *et al.*, 1993a). In fact, the high-amylose Australian rice, Doongara, is being marketed by Sunrice in 1998 as a "healthy" rice (functional food) that is suitable for diabetics (low glycemic index) (Jolly, 1998). A very-high-amylose rice (*amylose-extender* mutant) (35-40% amylose) did not have low glycemic index and high total resistant starch (2.8%) in cooked rice (Eggum *et al.*, 1993b), unlike corn ae starch which has 40% total dietary fiber (Yue and Waring, 1998). Glycemic index of a diet is calculated from the glycemic indexes of the component foods.

Whereas the rat readily digests raw starch (tables 6 and 7), man requires that the starch be cooked for digestion (Bornet *et al.*, 1989). Cooked starch is readily digested by man, as shown by the low levels of

Table 14. *Glycemic Index and* In Vivo *(Ileostomate) and* In Vitro *Resistant Starch ± SE and Apparent Amylose Content of Starch in Various Cooked and Baked Food Commodities.*

Food	Glycemic index[a] (% of Glucose / Bread)		Resistant starch		Apparent amylose[a] (%)
			In vivo[b]	*In vitro*[c]	
			(% of total starch)		
Rice, brown	55±5	79±6(3)		trace	15-30
Rice, milled	56±2	81±3(13)	3.9	trace	15-30
Rice, mllled parboiled	47±3	68±4(13)	3.6±0.9		15-30
Rice, low amylose/waxy	88±3	126±4(3)			0-2/15-20
Rice, high amylose	59±3	83±5(3)			20-30
Rice, instant	91±4	128±4(2)	5.1		15-25
Rice cakes	86±9	123±6(2)			15-20
Rice, puffed	86±7	123±11(3)		0.2	15-20
Rice Chex cereal	89	103±3(15)	2.9		15-20
Wheat, white bread	70±0	101±0(12)	5.4±0.8	0.8, 2	24-30
Wheat, whole bread	69±2	99±3(5)	7.8	0.7, 2	24-30
Spaghetti, white	41±3	59±4(10)	4.6	0.5, 1	24-30
Macaroni, white	45	64±8(1)	6.5	0.6	24-30
Uppuma(wheat semolina)	74±9	78±9(1)			24-30
Bulgur wheat	48±2	68±3(4)	6.4±1.1		24-30
Biscuit with 50% raw banana				38	20-23
Biscuit with 50% raw potato				35	24-27
Cornmeal	68	98±1(3)		0.1	28
Corn flakes	84±3	119±5(4)		2.9	28
Corn Chex cereal	83	103±3(15)	2.5		28
Popcorn	55±7	79(1)			28
Corn chips	73±1	105±2(2)			28
Corn starch, high-AC		59		40	50-70
Sweet corn	55±1	78±2(2)			29-33[d]
Rolled/cracked barley	69±3	94(2)			22,30
Pearled barley	25±2	36±3(4)	13.0±1.3		22
Barley whole bread	34±4	49±5(3)			22
Barley flour bread	66±1	95±2(3)			22
Couscous	65±8	93±9(2)			23-28
Millet	71±10	86±15(2)			23-28
Rye, whole	34±3	48±4(3)		0.2	24-30
Rye whole bread	50±2	71±3(6)		0.8	24-30
Rye flour bread	65±2	92±3(10	3.9	0.8	24-30
Oat bran cereal	55±6	78±8(2)	10.2±1.8		23-26
Oat porridge	61±2	87±2(8)		0.2	23-26
Mean	**63±3**	**86±5**	**5.8±1.2**	**0.6/38**	**28**

Table 14 (*continued*).

Food	Glycemic index[a] (% of		Resistant starch		Apparent amylose[a] (%)
	Glucose /	Bread)	*In vivo*[b] (% of total starch)	*In vitro*[c]	
Soybean	17±3	23±3(3)		6.1	
Mung bean noodles	26	45			35
Peanut snack	14±8	21±12(3)		6.2	
Beans, dried, cooked	48±8	69±12(2)		3.0, 8	32-36
Bean soups, various	58	84±7(4)			32-36
Broadbean		54±8(5)		6.5	24
Kidney bean, red, canned	52	70±5(2)	13.0	15	30-35
Chickpea, canned	42	59±1(2)	16.3	4.1,14	32-46
Green peas,	48±5	68±7(3)		4.5	33-36
Green peas, dried	39±8	56±12(2)		5.1	33-36
Lentils, red	26±4	38±3(6)	13.6±2.1	3.8	21-46
Lentils, green	30±4	42±6(8)		1.9	21-46
Idli (rice:dehulled black gram, fermented)	88±5	93±5(1)			30
Pongal (rice: dehulled green gram)	79±7	83±7(1)			30
Mean	**44±6**	**58±7**	**14.3**	**6.4**	**33**
Potato, new	62±7	81±8(3)		1.1	23
Potato, instant	83±1	118±2(5)	5.4	1.0	23
Potato, baked	85±12	121±16(4)		1.4	23
Potato, white, boiled	56±1	80±2(3)		1.2	23
Potato, white, mashed	70±2	100±2(3)		1.1	23
Potato, French fries	75	107±6(1)		2.2	23
Potato chips	54±3	77±4(2)		2.1	23
Sweet potato	54±8	77±11(2)		2.3	13-24
Tapioca	70±10	115±9(1)		0.4, 0.6	13-21
Taro	54	77			13-24
Yam	51±12	62±11(2)		1.4	14-27
Mean	**65±6**	**92±7**		**1.3**	**21**
Plantain, raw				1.3	20-21
Banana, ripe	59±6	83±6(5)		1.1	16
Banana, underripe	30	51±8(2)			16
Banana, overripe	52	82±8(2)			16
Mean	**47**	**72±8**		**1.2**	**17**

[a] FAO (1998); Foster-Powell and Brand Miller (1995); Jenkins *et al.* (1981); Thorne *et al.* (1983); Thompson *et al.* (1984); Viswanathan *et al.* (1988).

[b] Ileostomate (Jenkins *et al.*, 1987).

[c] Englyst and Kingman (1990); Holland *et al.* (1991); Englyst and Cummings (1986) resistant starch/Englyst dietary fiber.

[d] With 25% phytoglycogen.

resistant starch that reaches the large intestine and are fermented there into volatile fatty acids (Eggum *et al.*, 1993a) (table 14). Resistant starch is measured in ileostomates and in rats fed available carbohydrates with added antibiotic to suppress gut microflora. Resistant starch is essentially linear maltooligosaccharides with a degree of polymerization of about 60 glucose units and acts as a functional soluble dietary fiber in the large intestine. Resistant starch is higher in legumes than in cereals and roots and tubers. High values (>10%) for *in vivo* resistant starch were reported for pearled barley, oat bran cereal, canned chickpea and kidney bean and red lentil. High *in vitro* resistant starch values (35-40%) were reported for high-amylose corn starch and biscuit made with 50% raw banana flour or raw potato starch. Resistant starch in milled rice measured in rats is higher in high (>25%)-amylose and in higher gelatinization-temperature (GT >70°C) starch and is increased by cooking (Eggum *et al.*, 1993a). Starches with high resistant starch content in food applications have been developed from high-amylose corn starch (Yue and Waring, 1998).

Parboiling or pregelatinization of rice reduces glycemic index only in starches with intermediate- and high-amylose but not in waxy and low-amylose rices (Panlasigui, 1989; Miller *et al.*, 1992; Wolever *et al.*, 1986), corresponding to amylose levels (>20%) wherein the parboiled rice has harder cooked rice (Biswas and Juliano, 1988) and more amylose-lipid complex (Biliaderis *et al.*, 1993) than raw rice. By contrast, parboiling of high-amylose rice increased resistant starch of cooked low-GT rice but reduced resistant starch of cooked intermediate-GT rice in growing rats (Eggum *et al.*, 1993a).

Epidemiological and laboratory-animal model studies have suggested an inverse relationship between colon cancer risk and intake of fiber-rich foods. Both *in vitro* and *in vivo* experiments have shown striking chemopreventive potential for phytic acid and *myo*-inositol present in dietary fiber (Tsuno Foods and Rice, 1998). Soluble dietary fiber, including resistant starch, is fermented into short chain fatty acids in the colon and absorbed, whereas the insoluble dietary fiber provides bulk to feces (FAO, 1998) (table 3).

Soluble ß-glucans of oats and barley brans (>5%) have hypocholesterolemic activity (Jezequel, 1998). By contrast, in rice bran, only the unsaponifiable fraction of the oil but not the soluble ß-glucan (<1%) has hypocholesterolemic activity (Jezequel, 1998).

LIPIDS: ESSENTIAL FATTY ACIDS AND UNSAPONIFIABLE FRACTION

The amount of dietary linoleic acid found to prevent deficiency symptoms is 1-2% of dietary energy (National Research Council, 1989). However, both linoleic acid (n-6) and linolenic acid (n-3) are needed in the diet, preferably in a 5-10:1 ratio (FAO, 1994). Most lipids of cereals and legumes are rich in essential polyunsaturated fatty acids (EFA), linoleic, linolenic and arachidonic, except coconut (1%) (table 15). Linoleic acid is the principal EFA in all commodities except kidney bean (43% linolenic, 28% linoleic). Soybean and peanut are rich in EFA due to their high oil content. Roots, tubers, plantain and banana are lowest in EFA content.

The high unsaponifiable matter of rice oil (3-8%) has hypocholesterolemic activity (Nicolosi *et al.*, 1994). Ferulic acid derivatives such as *gamma*-oryzanol and cycloartenyl ferulate in rice grain show antioxidative activity. Rice oil is also rich in tocotrienols (0.3-0.4% *gamma*-tocotrienol, 0.2% *alpha*-tocotrienol) together with palm oil (0.07% *delta*-tocotrienol) which, apart from vitamin E activity, manifest a hypocholesterolemic effect (FAO, 1994). Rice oil is also rich in phytosterols that may inhibit absorption of cholesterol and bile acids: 0.5% campesterol, 0.3% stigmasterol and 0.9% ß-sitosterol. Variety and processing affect the content of unsaponifiable matter, particularly oryzanol and tocotrienols, of rice bran oil (Nicolosi *et al.*, 1994).

MICRONUTRIENTS: VITAMINS AND MINERALS

Staple foods are a major source of vitamins and minerals in the diet due to the large amount consumed, as evident in food consumption surveys. Yellow corn, yellow sorghum, yellow sweet potato, plantain and bananas are rich in vitamin A (carotene) (table 16). Legumes are highest in vitamin E and calcium and contain ascorbic acid. Roots are lowest in B vitamins, vitamin E, iron and zinc but have more ascorbic acid than the other commodity groups. Whole-grain cereals are richer in micronutrients than decorticated grains, but availability is higher in processed grain such as milled rice, due either to high dietary fiber or high phytate, and consumption of brown rice results in negative calcium balance (Juliano, 1993).

Recommended dietary allowances are 375-1000 µg retinol (2.25-6.0 mg ß-carotene), 6-30 mg iron and 5-19 mg zinc (National Research Council, 1989). Mineral availability to man from vegetative source is lower than from animal source. For example, iron bioavalability from a Filipino rice meal was 6.9% and was 5.4% with iron fortification (Valdez *et al.*, 1996). Folic acid enrichment of grain in the United States became in effect in 1998 to reduce the risk of neural tube birth defects (Hoffpauer and Bonnette, 1998).

Table 15. *Content of Essential Fatty Acids (EFA) of Various Food Commodities* (USDA, 1998; Holland *et al.*, 1991; FAO-USDA, 1982).

Commodity	Linoleic	Linolenic	Total EFA	
		(% of total fatty acids)		(g/100 g EP)
Brown rice	33	1	35	0.94
Wheat	44	3	47	0.83
Corn	51	2	53	2.08
Barley	53	6	59	1.05
Sorghum	46	2	48	1.30
Millet	56	3	59	2.01
Rye	56	9	65	1.08
Oat	41	2	43	2.38
Triticale	57	4	61	0.88
Mean	**49**	**4**	**52**	**1.39**
Soybean	54	7	61	11.3
Mung bean	40	3	43	0.38
Peanut	33	0	33	15.56
Broadbean	49	4	53	0.63
Kidney bean	28	43	71	0.46
Chickpea	55	2	58	2.69
Green pea	46	9	55	0.50
Lentil	47	13	60	0.45
Coconut, dried	1	0	1	0.71
Mean	**39**	**9**	**48**	**3.63**
Potato	45	14	61	0.043
Sweet potato	54	10	64	0.13
Cassava	16	9	24	0.05
Tapioca	15	8	23	0.003
Yam	54	10	64	0.08
Taro	41	18	59	0.08
Plantain	18	10	28	0.07
Banana	18	10	28	0.09
Mean	**33**	**11**	**44**	**0.07**

Table 16. *Content of Vitamins and Minerals of Cereals, Legumes and Starchy Roots and Bananas per 100 Grams Edible Portion* (USDA, 1998).

Food	Vitamin A (mg retinol)	Thiamine (mg)	Riboflavin (mg)	Niacin (mg)	Ascorbic acid (mg)	Vitamin E (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)
Brown rice	0	0.40	0.04	4.2	0	0.65	32	3	2
Wheat	0.02	0.43	0.11	5.5	0	1.42	27	4	3
Corn	0.045	0.37	0.19	3.5	0	0.72	7	3	2
Barley	0.002	0.61	0.27	4.4	0	0.57	31	3	3
Sorghum	0	0.22	0.13	2.8	trace	0.17	28	4	2
Millet	0	0.40	0.27	4.7	0	0.17	8	3	2
Rye	0	0.30	0.24	4.1	0	1.81	32	3	4
Oats	0	0.72	0.13	0.9	0	0.66	54	4	4
Triticale	0	0.40	0.13	1.4	0	0.86	36	3	3
Mean	**0.007**	**0.43**	**0.15**	**3.5**	**0**	**0.78**	**28**	**3**	**3**
Soybean	0.002	0.87	0.87	1.6	6	1.95	277	16	5
Mung bean	0.011	0.62	0.23	2.3	5	0.51	132	7	3
Peanut	0.020	0.64	0.14	12.1	11	9.13	92	5	3
Broadbean	0.005	0.56	0.33	2.8	1.4	0.09	103	7	3
Kidney bean	0.001	0.53	0.22	2.1	4.5	0.2	143	8	3
Chickpea	0.007	0.48	0.21	1.5	4.0	0.82	105	6	3
Green pea	0.015	0.73	0.22	2.9	1.8	0.30	55	4	3
Lentil	0.004	0.48	0.24	2.6	6.2	0.33	51	9	4
Coconut	0	0.06	0.10	0.6	2	1.35	26	3	2
Mean	**0.007**	**0.46**	**0.28**	**3.2**	**5**	**1.63**	**109**	**7**	**3**
Potato	0.01	0.11	0.05	1.2	20	0.06	7	0.8	0.4
Sweet potato	2.0	0.07	0.15	0.7	23	0.28	22	0.6	0.3
Cassava	0.002	0.06	0.05	0.9	21	0.19	16	0.3	0.3
Yam	0.0	0.11	0.03	0.6	17	0.16	17	0.5	0.2
Taro	0.0	0.10	0.02	0.6	4.5	2.38	43	0.6	0.2
Plantain	0.11	0.05	0.05	0.7	18.4	0.27	3	0.6	0.14
Banana	0.008	0.04	0.10	0.5	9.1	0.27	6	0.3	0.2
Mean	**0.30**	**0.08**	**0.06**	**0.7**	**16**	**0.52**	**16**	**0.4**	**0.2**

ACCEPTABILITY AND ANTINUTRITION FACTORS

Quality Factors

Protein content and gluten quality determine acceptability of wheat and rye in bread. The pentosans of rye also affect bread quality. But the starch fraction of wheat varieties has similar properties. The 7S globulin of soybean determines functional properties, such as emulsifying capacity and emulsion stability of products (Kitamura, 1995).

The starch fraction (amylose:amylopectin ratio) influences texture in the other staple foods such as rice, with cooked food hardness increasing with amylose content. Low starch GT is also critical in baked products in the presence of sugars that elevate GT of starch in the dough with limited free water. Sorghum and legume starches are hard to cook.

Some roots such as potato have saponins and tannins that contribute to a bitter taste (FAO, 1990). The high content of calcium oxalate crystals (about 780 mg/100 g) has been implicated in the acridity or irritation caused by taro (FAO, 1990). Bird-resistant sorghums are also rich in tannins.

Antinutrition Factors

Antinutrition factors that affect protein nutrition include protease inhibitors: trypsin inhibitors, hemagglutinins (lectins) and cystatins in legumes (FAO, 1982) and cereals that are concentrated in the embryo and seed coat. Among root crops, giant taro has a much higher trypsin inhibitor content than sweet potato, taro and giant swamp taro (Bradbury and Holloway, 1988). They are denatured by heating, particularly wet heating and extrusion. The trypsin inhibitor in rice bran has an effect mainly on poultry and has no effect on monogastric animals (Eggum *et al.*, 1984). Tannins and phytin also reduce TD by complexing with human proteases.

Antinutrition factors that affect starch digestion include amylase inhibitors present in cereals, tannin and phytin. Brown rice has lower glycemic index than milled rice for this reason (Panlasigui, 1989). Flatulence factors present in legumes and sweet potato include galactose-containing oligosaccharides, raffinose, stachyose and verbascose (table 3), which are not metabolized by man and are fermented by bacteria in the large intestine.

Some varieties of root crops (cassava) have a toxic cyanogenic glycoside, linamarin and methyl linamarin, that release HCN on hydrolysis, causing death to consumers (FAO, 1990). Several diseases have been associated with the toxic effects of cassava: acute cyanide intoxication, endemic goiter, tropical ataxic neuropathy, and epidemic spastic paraparesis (FAO, 1990).

Mycotoxins, particularly aflatoxins, are important in corn, peanut and coconut due to their prolonged exposure to high moisture before or after harvest.

ENHANCEMENT OF NUTRITIONAL VALUE: BREEDING AND POSTHARVEST TECHNIQUES; FUNCTIONAL FOODS AND NUTRACEUTICALS

Breeding Approach

Breeding efforts in the 1960s and 1970s attempted to improve the protein content and limiting amino acid (lysine content in cereals and cystine and methionine in legumes) of staple foods, both of which require more energy to produce from glucose than nonessential amino acids (Mitra *et al.*, 1979):

Production value (PV = wt of endproduct/wt of substrate (glucose) required for carbon skeleton and energy production):

Glutamic acid PV = 0.7054
Lysine PV = 0.3952
Cysteine PV = 0.4913
Methionine PV = 0.4309

In addition, most energy is required for lipid synthesis (PV = 0.351), followed by protein (PV = 0.604) and then carbohydrate (PV = 0.853) (Penning de Vries *et al.*, 1974). Biotechnology is being used to improve the nutritive value of rice protein by reducing prolamin/increasing glutelin to improve digestibility and amino acid score, and reducing also the allergenic proteins in rice endosperm.

In soybean, 7S and 11S globulins account for 70% of seed protein. Increase in 7S globulin improves functional properties, whereas increase in 11S globulin improves nutritive value since it has 3-4 times more methionine and cystine than 7S globulin (Kitamura, 1995).

Genetic manipulation of starch properties are being pursued using multiple starch mutants in corn, and waxy wheat and potato starches to improve food applications (Hermansson and Svegmark, 1996). High dietary fiber (resistant starch) corn starches have been introduced in the market (Yue and Waring, 1998).

The Consultative Group for International Agricultural Research recently launched a project to increase the micronutrient density of selected crops, particularly vitamin A, iron and zinc (Graham and Welch, 1996), although mineral absorption from vegetable source is poor. An estimated 2 billion people live at risk to diseases resulting from deficiencies of vitamin A, iodine and iron, mostly women and children in developing countries (Coombs *et al.*, 1996). A vitamin A-rich rice may have yellow color, similar to stack-burned milled rice (Eggum *et al.*, 1984). Some rice cultivars are more efficient in extracting Zn from Zn-deficient soils and even normal soils. A complementary approach to improved mineral absorption is through the low phytate mutant of cereals (Raboy, 1996) that may improve not only mineral absorption but also protein digestibility and glycemic index. By contrast, the First International Symposium on Disease Prevention by Phytate and other Rice Components held in Kyoto on June 8-9, 1998 summarized the disease preventive properties of rice phytate (Tsuno Foods and Rice, 1998).

Postharvest Techniques

Decortication or abrasive milling of cereals or dehulling of legumes reduces the levels of antinutrition factors in the resulting inner fraction: trypsin inhibitor, tannin and phytin. Digestibility of energy and protein increases with degree of milling. Dietary fiber content also decreases with milling. Cooking improves starch digestibility in man (Bornet *et al.*, 1989) and reduces phytin content. Leavening results in partial hydrolysis of phytin by phytase: stunting from Zn deficiency is prevalent in areas consuming unleavened bread.

Improved shelflife through reduced lipid oxidation is being pursued. Soybean lacking lipoxygenase involved in fatty acid oxidation improves shelflife of the oil fraction but lacks the characteristic oxidized odor (hexanal) of rancid soybean (Kitamura, 1995). Low linolenate (from 8% to 2-3.5%) soybeans were developed through mutation at Iowa State University (Hammond and Fehr, 1998). Rice mutant lacking lipoxygenase 3 (Suzuki *et al.*, 1996) may likewise reduce fat rancidity and maintain essential fatty acid level of rice during storage. High-oil corn and high-stearate, low-linoleate corn have also been obtained by DuPont Company by transgenic approach (Shen, 1998).

Functional Foods and Nutraceuticals

Functional foods and nutraceuticals are becoming more important in the food market in developed countries and would probably impact on developing countries. In addition to vitamins, data during the last decade have shown that grains, vegetables and fruits contain a variety of potentially chemopreventive substances called phytochemicals. A major group of phytochemicals in foods with antioxidative power are the phenolic compounds, which include plant flavonoids, phytosterines, saponins, and phytoestrogens (Andlauer and Furst, 1998). The major source of dietary phytoestrogens, isoflavone and lignans, are the cereals (at 2-8 mg/kg) being the staple food. Soybean-protein products are rich in isoflavone (1 g/kg). Triterpene and steroid saponins occur primarily in legumes (Lásztity *et al.*, 1998). Consumption of 400-800 g/day of a variety of vegetables and fruits is recommended to prevent cancer (WCRF/AICR, 1997). Selenium supplementation also reduces the incidence of prostate cancer (Clarke *et al.*, 1998)

The First International Symposium on Disease Prevention by IP_6 (Phytic Acid) and Other Rice Components held in Kyoto, Japan, on 8-9 June 1998, summarized the anticancer action of phytic acid and its contribution to the protective effect of high fiber diet against cardiovascular diseases, together with other rice antioxidants, tocopherols, oryzanols, and vitamins (Tsuno Foods and Rice, 1998). Phytate inhibits renal stone formation. Gamma-oryzanol and ferulic acid derivatives have anticancer activity and lower cholesterol level. Gamma-aminobutyric acid (GABA)-rich rice germ lowers blood pressure: GABA is derived from glutamic acid decarboxylation by glutamic acid decarboxylase. Healthy ingredients and foods from rice were recently reviewed (Obanni *et al.*, 1998).

The adoption of GATT-WTO worldwide has triggered renewed interest on value-added convenience food products with improved quality and shelflife for export to niche markets. As populations improve in purchasing power, their staple foods tend to shift from roots, tubers, plantain and bananas to cereals, and later on from rice and corn to wheat products with higher fat content. In countries such as Japan, South Korea and Taiwan, China, efforts are being made to maintain rice production by offsetting the declining consumption of table rice by the development and increased consumption of new value-added rice food products and convenience foods.

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REFERENCES

Agarwal, K.N., Bhatia, B.D., Agarwal, D.K., and Shankar, R. (1984): 'Assessment of Protein Energy Needs of Indian Adults Using Short-Term Nitrogen Balance Methodology', in *Protein-Energy-Requirement Studies in Developing Countries: Results of International Research*, eds. W.M. Rand, R. Uauy and N.S. Scrimshaw (Tokyo, United Nations University), pp. 89-95.

Andlauer, W., and Fuerst, P. (1998): 'Antioxidative Power of Phytochemicals with Special Reference to Cereals', *Cereal Foods World*, 43, pp. 356-360.

Beames, R.M., and Eggum, B.O. (1981): 'The Effect of Type and Level of Protein, Fibre and Starch on Nitrogen Excretion Patterns in Rats', *British Journal of Nutrition*, 46, pp. 301-313.

Bechtel, D.B., and Juliano, B.O. (1980): 'Formation of Protein Bodies in the Starchy Endosperm of Rice (*Oryza sativa* L.): a Re-investigation', *Annals of Botany*, 45, pp. 503-509.

Biliaderis, C.G., Tonogai, J.R., Perez, C.M., and Juliano, B.O. (1993): 'Thermophysical Properties of Milled Rice Starch as Influenced by Variety and Parboiling Method', *Cereal Chemistry*, 70, pp. 512-516.

Biswas, S.K., and Juliano, B.O. (1988): 'Laboratory Parboiling Procedures and Properties of Parboiled Rice from Varieties Differing in Starch Properties', *Cereal Chemistry*, 65, pp. 417-423.

Bornet, F.R.J., Fontevieille, A.M., Rizkalla, S., Colonna, P., Blayo, A., Mercier, C., and Slama, G. (1989): 'Insulin and Glycemic Responses in Healthy Humans to Native Starches Processed in Different Ways: Correlation with in Vitro Âpha-Amylase Hydrolysis', *American Journal of Clinical Nutrition*, 50, pp. 315-323.

Bourges R.H., and Lopez-Castro, B.R. (1981): 'Protein Requirements of Young Male Adults with a Rural Mexican Diet', in *Protein-Energy Requirements of Developing Countries: Evaluation of New Data*, eds. B. Torún, V.R. Young and W.M. Rand (Tokyo, United Nations University), pp. 71-76.

Bradbury, J.H., and Halloway, W.D. (1988): *Chemistry of Tropical Root Crops: Significance for Nutrition and Agriculture in the Pacific* (Canberra, Australian Centre for International Agricultural Research).

Bressani, R., Navarrete, D.A., Vargas, E., and Gutierrez, O. (1981): 'Protein Needs of Young Adult Men Fed Common Beans (*Phaseolus vulgaris*) in Combination with Starch, Plantain, Maize, or Rice', in *Protein-Energy Requirements of Developing Countries: Evaluation of New Data*, eds. B. Torún, V.R. Young and W.M. Rand (Tokyo, United Nations University) Food and Nutrition Bulletin Supplement, 5, pp. 108-114.

Cabrera-Santiago, M.I., Intengan, C.Ll., Roxas, B.V., Juliano, B.O., Perez, C.M., Loyola, A.S., Alejandro, E.R., Abadilla, J.N., Yu, G.F.B., and Mallillin, A.C. (1986): 'Protein Requirements of Preschool Children Consuming Rice-Milk, Rice-Toasted Mung Bean, and Rice Diets', *Qualitas Plantarum: Plant Foods for Human Nutrition*, 36, pp. 167-178.

Calloway, D.H. (1995): *Human Nutrition: Food and Micronutrient Relationships* (Washington, D.C., International Food Policy Research Institute) Agricultural Strategies for Micronutrients Working Paper No. 1.

Chandler, S. (1995): 'The Nutritional Value of Bananas', in *Bananas and Plantains*, ed. S. Gowen (London, Chapman and Hall), pp. 468-480.

Chen, X., Yin, T., Yang, X., Bai, J., and Huang, Z. (1984): 'Protein Requirements of Chinese Male Adults', in *Protein-Energy-Requirement Studies in Developing Countries: Results of International Research*, eds. W.M. Rand, R. Uauy and N.S. Scrimshaw (Tokyo, United Nations University), pp. 96-101.

Clark, L.C., Dalkin, B., Krongrad, A., Combs, Jr., G.F., Turnbull, B.W., Slate, E.H., Witherington, R., Herlong, J.H., Janosko, E., Carpenter, D., Borosso, C., Falk, S., and Rounder, J. (1998): 'Decreased Incidence of Prostate Cancer with Selenium Supplementation: Results of a Double Blind Cancer Prevention Trial', *British Journal of Urology*, 81, pp. 730-734.

Combs, Jr., G.F., Welch, R.M., Duxbury, J.M., Uphoff, N.T., and Nesheim, M.C. (eds.) (1996): *Food-Based Approaches to Preventing Micronutrient Malnutrition: An International Agenda, Summary Report of an International Workshop, Salt Lake City, Nov. 6-9, 1995* (Ithaca, NY, USA, Cornell International Institute for Food, Agriculture and Development, Cornell University).

Deshpande, S.S., and Damodaram, S. (1990): 'Food Legumes: Chemistry and Technology', *Advances in Cereal Science and Technology*, 10, pp. 147-241.

Dutra de Oliveira, J.E., and Vannucchi, H. (1984): 'The Protein Requirements of Brazilian Rural Workers: Studies with a Rice and Bean Diet', in *Protein-Energy-Requirement Studies in Developing Countries: Results of International Research*, eds. W.M. Rand, R. Uauy and N.S. Scrimshaw (Tokyo, United Nations University), pp. 111-118.

Egaña M.J.I., Fuentes, A., and Uauy, R. (1984): 'Protein Needs of Chilean Pre-school Children Fed Milk and Soy Protein Isolate Diets', in *Protein-Energy-Requirement Studies in Developing Countries: Results of International Research*, eds. W.M. Rand, R. Uauy and N.S. Scrimshaw (Tokyo, United Nations University), pp. 249-257.

Eggum, B.O. (1969): 'Evaluation of Protein Quality and the Development of Screening Techniques', in *New Approaches to Breeding for Improved Plant Protein* (Vienna, International Atomic Energy Agency), pp. 125-135.

Eggum, B.O. (1973): *A Study of Certain Factors Influencing Protein Utilization in Rats and Pigs* (Copenhagen, Institute of Animal Science), 173 pp.

Eggum, B.O., Brunsgaard, G., and Jensen, J. (1995): 'The Nutritive Value of New High-Lysine Barley Mutants', *Journal of Cereal Science*, 22, pp. 171-176.

Eggum, B.O., Cabrera, M.I.Z., and Juliano, B.O. (1993c): 'Protein and Lysine Digestibility and Protein Quality of Cooked Filipino Rice Diets and Milled Rice in Growing Rats', *Plant Foods for Human Nutrition*, 43, pp. 163-170.

Eggum, B.O., Dumanovic, J., Misevic, D., and Denic, M. (1983a): 'Grain Yield and Nutritive Value of High Oil, Opaque and Waxy Maize Hybrids', *Journal of Cereal Science*, 1, pp. 139-145.

Eggum, B.O., Hansen, I., and Larsen, T. (1989): 'Protein Quality and Digestible Energy of Selected Foods Determined in Balance Trials with Rats', *Plant Foods for Human Nutrition*, 39, pp. 13-21.

Eggum, B.O., and Juliano, B.O. (1973): 'Nitrogen Balance in Rats Fed Rices Differing in Protein Content', *Journal of the Science of Food and Agriculture*, 24, pp. 921-927.

Eggum, B.O., Juliano, B.O., Ibabao, M.G.B., Perez, C.M., and Carangal, V.R. (1987): 'Protein and Energy Utilization of Boiled Rice-Legume Diets and Boiled Cereals in Growing Rats', *Plant Foods for Human Nutrition*, 37, pp. 237-245.

Eggum, B.O., Juliano, B.O., Perez, C.M., and Acedo, E.F. (1993a): 'The Resistant Starch, Undigestible Energy and Undigestible Protein Contents of Raw and Cooked Milled Rice', *Journal of Cereal Science*, 18, pp. 159-170.

Eggum, B.O., Juliano, B.O., Perez, C.M., and Khush, G.S. (1993b): 'Starch, Energy, and Protein Utilization by Rats in Milled Rice of IR36-Based Amylose Extender Mutant', *Cereal Chemistry*, 70, pp. 275-279.

Eggum, B.O., Monowari, L., Bach Knudsen, K.E., Munck, L., and Axtell, J. (1983b): 'Nutritional Quality of Sorghum and Sorghum Foods from Sudan', *Journal of Cereal Science*, 1, pp. 127-137.

Eggum, B.O., Resurreccion, A.P., and Juliano, B.O. (1977): 'Effect of Cooking on Nutritional Value of Milled Rice in Rats', *Nutrition Reports International*, 16, pp. 649-655.

Eggum, B.O., Villareal, C.P., Perez, C.M., and Juliano, B.O. (1984): 'Effect of Treatment on Composition and Protein and Energy Utilization of Rice and Mung Bean by Rats', *Qualitas Plantarum Plant Foods for Human Nutrition*, 34, pp. 261-272.

Englyst, H.N., and Cummings, J.H. (1986): 'Digestion of the Carbohydrates of Banana (Musa paradisiaca sapientum) in the Human Small Intestine', *American Journal of Clinical Nutrition*, 44, pp. 42-50.

Englyst, H.N., and Kingman, S.M. (1990): 'Dietary Fibre and Resistant Starch. A Nutritional Classification of Plant Polysaccharides', in *Dietary Fiber*, eds. D. Kritchevsky, C. Bonfield and J.W. Anderson (New York, Plenum Press).

Eppendorfer, W.H., Eggum, B.O., and Bille, S.W. (1979): 'Nutritional Value of Potato Crude Protein as Influenced by Manuring and Amino Acid Composition', *Journal of the Science of Food and Agriculture*, 30, pp. 361-368.

Fajardo, L.F., Bolanos, O., Acciarri, G., Victoria, F., Restrapo, J., Ramirez, A.M., and Angel, L.M. (1981): 'Protein Requirements for Young Colombian Adults Consuming Local Diets Containing Primarily Animal or Vegetable Protein', in *Protein-Energy Requirements of Developing Countries: Evaluation of New Data*, eds. B. Torún, V.R. Young and W.M. Rand (Tokyo, United Nations University), pp. 54-62.

FAO (1982): *Legumes in Human Nutrition* (Rome, Food and Agriculture Organization), Food and Nutrition Paper 20.

FAO (1990): *Roots, Tubers, Plantains and Bananas in Human Nutrition* (Rome: Food and Agriculture Organization), Food and Nutrition Series No. 24.

FAO (1991): *Protein Quality Evaluation. Report of Joint FAO/WHO Expert Consultation, Bethesda, MD, 1989* (Rome, Food and Agriculture Organization) Food and Nutrition Paper 51.

FAO (1992): *Meat and Meat Products in Human Nutrition in Developing Countries* (Rome, Food and Agriculture Organization), Food and Nutrition Paper 53.

FAO (1994): *Fats and Oils in Human Nutrition* (Rome, Food and Agriculture Organization), Food and Nutrition Paper 57.

FAO (1996a): *The Sixth World Food Survey* (Rome, Food and Agriculture Organization) 153 pp.

FAO (1996b): 'FAO Indices of Food and Agricultural Production', *FAO Quarterly Bulletin of Statistics* 9 (3/4), pp. 114-115.

FAO (1997): 'FAO Indices of Food and Agricultural Production', *FAO Quarterly Bulletin of Statistics* 10 (1/2) 13-59, pp. 69-70.

FAO (1998): *Carbohydrates in Human Nutrition* (Rome, Food and Agriculture Organization), Food and Nutrition Paper 66.

FAO-USDA (1982): *Food Composition Tables for the Near East* (Rome, Food and Agriculture Organization - Hyattsville, MD, USA, United States Department of Agriculture Human Nutrition Information Service) 265 pp.

Foster-Powell, K., and Brand Miller, J. (1995): 'International Tables of Glycemic Index', *American Journal of Clinical Nutrition*, 62, pp 869S-893S.

Goddard, M.S., Young, G., and Marcus, R. (1984): 'The Effect of Amylose Content on Insulin and Glucose Responses to Ingested Rice', *American Journal of Clinical Nutrition*, 39, pp. 388-392.

Graham, G.G. (1971): 'Methionine or Lysine Fortification of Dietary Protein for Infants and Small Children', in *Amino Acid Fortification*, eds. N.S. Scrimshaw and A.T. Altschul (Cambridge, Massachussets, MIT Press), pp. 222-236.

Graham, G.G., Glover, D.V., Lopez de Romaña, G., Morales, E., and MacLean, W.C., Jr. (1980): 'Nutritional Value of Normal, Opaque-2 and Sugary-2 Opaque-2 Maize Hybrids for Infants and Children. I. Digestibility and Utilization', *Journal of Nutrition*, 110, pp. 1061-1069.

Graham, G.G., MacLean, W.C., Jr., and Morales, E. (1990): 'The Nutritional Value of Oat Flour for Very Young Children', *Journal of Pediatric Gastroenterology and Nutrition*, 10, pp. 344-350.

Graham, G.G., Morales, E., Placko, R.P., and MacLean, W.C., Jr. (1979): 'Nutritive Value of Brown and Black Beans for Infants and Small Children', *American Journal of Clinical Nutrition*, 32, pp. 2362-2366.

Graham, G.G., Lembcke, J., Lancho, E., and Morales, E. (1989): 'Quality Protein Maize Digestibility and Utilization by Recovering Malnourished Infants', *Pediatrics*, 83, pp. 416-421.

Graham, R.D., and Welch, R.M. (1996): *Breeding for Staple Food Crops with High Micronutrient Density* (Washington, D.C., International Food Policy Research Institute) Agricultural Strategies for Micronutrients Working Paper 3, 79 pp.

Hammond, E.G., and Fehr, W.R. (1998): 'The Development and Marketing of Soybeans with Special Compositions at Iowa State University (abstract)', *Cereal Foods World*, 43, pp. 509-510.

Heger, J., and Eggum, B.O. (1991): 'The Nutritional Value of Some High-Yielding Cultivars of Triticale', *Journal of Cereal Science*, 14, pp. 63-71.

Hermansson, A.-M., and Svegmark, K. (1996): 'Developments in the Understanding of Starch Functionality', *Trends in Food Science and Technology*, 7, pp. 345-353.

Hoffpauer, D.W., and Bonnette III, R.E. (1998): 'Enrichment Update on Folic Acid', *Cereal Foods World*, 43, pp. 365-367.

Holland, B., Welch, A.A., Unwin, I.D., Buss, D.H., Paul, A.A., and Southgate, D.A.T. (1991): *McCance and Widdowson's The Composition of Foods*, 5th rev. ed. (Cambridge, UK, The Royal Society of Chemistry and Ministry of Agriculture, Fisheries and Food).

Huang, P.C., Lee, N.Y., and Chen, S.H. (1979): 'Evidences Suggestive of No Intestinal Nitrogen Fixation for Improving Protein Nutrition Status in Sweet Potato Eaters', *American Journal of Clinical Nutrition*, 32, pp. 1741-1750.

Huang, P.C., and Lin, C.P. (1982): 'Protein Requirements of Young Chinese Male Adults on Ordinary Chinese Mixed Diet and Egg Diet at Ordinary Level of Energy Intake', *Journal of Nutrition*, 112, pp. 897-907.

Inoue, G., Takahashi, T., Kishi, K., Komatsu, T., and Niiyama, Y. (1981): 'The Evaluation of Soy Protein Isolate Alone and in Combination with Fish in Adult Japanese Men', in *Protein-Energy Requirements of Developing Countries: Evaluation of New Data*, eds. B. Torún, V.R. Young and W.M. Rand (Tokyo, United Nations University), pp. 77-87.

Intengan, C.Ll. (1984): 'Protein Requirements of Filipino Children 22-29 Months Old Consuming Local Diets', in *Protein-Energy-Requirement Studies in Developing Countries: Results of International Research*, eds. W.M. Rand, R. Uauy and N.S. Scrimshaw (Tokyo, United Nations University), pp. 258-264.

Intengan, C.Ll., Roxas, B.V., Loyola, A., and Carlos, E. (1981): 'Protein Requirements of Filipino Children 20 to 29 Months Old Consuming Local Diets', in *Protein-Energy Requirements of Developing Countries: Evaluation of New Data,* eds. B. Torún, V.R. Young and W.M. Rand (Tokyo, United Nations University), pp. 172-181.

Intengan, C.Ll., Roxas, B.V., Santiago, M.I.C., and Juliano, B.O. (1982): 'Protein Requirements of Adult Filipino Consuming Local Diets', *Philippine Journal of Nutrition*, 35, pp. 112-119.

Jenkins, D.J.A., Cuff, D., Wolever, T.M.S., Knowland, D., Thompson, L., Cohen, Z., and Prokipchuk, E. (1987): 'Digestibility of Carbohydrate Foods in an Ileostomate: Relationship to Dietary Fiber, *in Vitro* Digestibility, and Glycemic Response', *American Journal of Gastroenterology*, 82, pp. 709-717.

Jenkins, D.J.A., Wolever, T.M.S., Taylor, R.H., Barker, H., Fielden, H., Baldwin, J.M., Bowling, A.C., Newman, H.C., Jenkins, A.L., and Goff, D.V. (1981): 'Glycemic Index of Foods: a Physiological Basis for Carbohydrate', *American Journal of Clinical Nutrition*, 34, pp. 362-366.

Jezequel, V. (1998): 'Curdlan: A New Functional ß-Glucan', *Cereal Foods World*, 43, pp. 361-364.

Jolly, J., 1998, 'Australia: Rice Takes a Turn into the Specialty Market', NewsView, Market Information and Research.

Juliano, B.O. (1993), *Rice in Human Nutrition* (Manila, International Rice Research Institute – Rome, Food and Agriculture Organization), FAO Food and Nutrition Series No. 26.

Juliano, B.O., and Goddard, M.S. (1986): 'Cause of Varietal Difference in Insulin and Glucose Responses to Ingested Rice', *Qualitas Plantarum Plant Foods for Human Nutrition*, 36, pp. 35-41.

Kitamura, K. (1995): 'Genetic Improvement of Nutritional and Food Processing Quality in Soybean', *Japan Agricultural Research Quarterly*, 20, pp. 1-8.

Larsen, H.N., Christensen, C., Rasmussen, O.W., Tetens, I., Choudhury, N.H., Thilsted, S.H., and Hermansen, K. (1996): 'Influence of Parboiling and Physico-chemical Characteristics of Rice on the Glycaemic Index (GI) in Non-Insulin-Dependent Diabetic (NIDDM) Subjects', *European Journal of Clinical Nutrition*, 50, pp. 22-27.

Lásztity, R., Hidvégi, M., and Bata, A. (1998): 'Saponins in Food', *Food Reviews International*, 14, pp. 371-390.

Lopez de Romaña, G., Graham, G.G., Mellits, E.D., and MacLean, W.C., Jr. (1980): 'Utilization of the Protein and Energy of the Potato by Human Infants', *Journal of Nutrition*, 109, pp. 1290-1298.

MacLean, W.C., Jr., Klein, G.L., Lopez de Romaña, G., Massa, E., and Graham, G.G. (1978): 'Protein Quality of Conventional and High-protein Rice and Digestibility of Glutinous and Nonglutinous Rice by Preschool Children', *Journal of Nutrition*, 108, pp. 1740-1747.

MacLean, W.C., Jr., Lopez de Romaña, G., and Graham, G.G. (1976): 'Protein Quality of High Protein Wheats in Infants and Children', *Journal of Nutrition*, 106, pp. 362-370.

MacLean, W.C., Jr., Lopez de Romaña, G., Klein, G.L., Massa, E., Mellits, E.D., and Graham, G.G. (1979): 'Digestibility and Utilization of the Energy and Protein of Wheat by Infants', *Journal of Nutrition*, 109, pp. 1290-1298.

MacLean, W.C., Jr., Lopez de Romaña, G., Placko, R.P., and Graham, G.G. (1981): 'Protein Quality and Digestibility of Sorghum in Preschool Children', *Journal of Nutrition*, 111, pp. 1928-1936.

Miller, J.B., Pang, E., and Bramall, L. (1992): 'Rice: a High or Low Glycemic Index Food?', *American Journal of Clinical Nutrition*, 56, pp. 1034-1036.

Mitra, R.K., Bhatia, C.R., and Rabson, R. (1979): 'Bioenergetic Cost of Altering the Amino Acid Composition of Cereal Grains', *Cereal Chemistry*, 56, pp. 249-252.

Morales, E., and Graham, G.G. (1987): 'Effect of Amounts Consumed on the Digestion of Cassava by Young Children', *Journal of Nutrition*, 117, pp. 2116-2120.

National Research Council (1989): *Recommended Dietary Allowances* (Washington, D.C., National Academy Press).

Nicol, B.M., and Phillips, P.G. (1978): 'The Utilization of Proteins and Amino Acids in Diets Based on Cassava (*Manihot utilissima*), Rice or Sorghum (*Sorghum sativa*) by Young Nigerian Men of Low Income', *British Journal of Nutrition*, 39, pp. 271-287.

Nicolosi, R.J., Rogers, E.J., Ausman, L.M., and Orthoefer, F.T. (1994): 'Rice Bran Oil and Its Health Benefits', in *Rice Science and Technology*, eds. W.E. Marshall and J.I. Wadsworth (New York, M. Dekker, Inc.), pp. 421-437.

Obanni, M., Mitchell, C., and Medcalf, D. (1998): 'Healthy Ingredients and Foods from Rice', *Cereal Foods World*, 43, pp. 696-698.

Omole, A., Adewusi, S.A., Adeyemo, A., and Oke, O.L. (1978): 'The Nutritive Value of Tropical Fruits and Root Crops', *Nutrition Reports International*, 17, pp. 575-580.

Ozalp, I., Ozgüc, M., Tokol, S., Koksal, G., Tasci, N., and Soysal, G. (1984): 'Nitrogen Balances of Young Turkish Adults on Graded Levels of Protein Intake', in *Protein-Energy-Requirement Studies in Developing Countries: Results of International Research*, eds. W.M. Rand, R. Uauy and N.S. Scrimshaw (Tokyo, United Nations University), pp. 107-110.

Panlasigui, L.N. (1989): *Glycemic Response to Rice* (Toronto, Ontario, Canada, University of Toronto Department of Nutritional Science, Ph.D. dissertation) 171 pp.

Panlasigui, L.N., Thompson, L.U., Juliano, B.O., Perez, C.M., Tiu, S.H., and Greenberg, G.R. (1991): 'Rice Varieties with Similar Amylose Content Differ in Starch Digestibility and Glycemic Response in Humans', *American Journal of Clinical Nutrition*, 54, pp. 871-877.

Penning de Vries, F.W.T., Brunsting, A.H.M., and van Laar, H.H. (1974): 'Products, Requirements and Efficiency of Biosynthesis: a Quantitative Approach', *Journal of Theoretical Biology*, 45, pp. 339-377.

Raboy, V. (1996): 'Cereal Low Phytic Mutants: A "Global" Approach to Improving Mineral Nutritional Quality', in *Micronutrients and Agriculture* (Washington, D.C., Federation of American Scientists), 2, pp. 15-16.

Resurreccion, A.P., Li, X., Okita, T.W., and Juliano, B.O. (1993): 'Characterization of Poorly Digested Protein of Cooked Rice Protein Bodies', *Cereal Chemistry*, 70, pp. 101-104.

Roxas, B.V., Intengan, C.Ll., and Juliano, B.O. (1975): 'Effect of Protein Content of Milled Rice on Nitrogen Retention of Filipino Children Fed a Rice-Fish Diet', *Nutrition Reports International*, 11, pp. 393-398.

Roxas, B.V., Intengan, C.Ll., and Juliano, B.O. (1976): 'Protein Content of Milled Rice and Nitrogen Retention of Preschool Children Fed Rice-Mungbean Diets', *Nutrition Reports International*, 14, pp. 203-207.

Salunkhe, D.K., and Kadam, S.S. (eds.) (1989): *CRC Handboook of World Food Legumes: Nutritional Chemistry, Processing Technology, and Utilization*, vol. I-III (Boca Raton, Florida, USA, CRC Press, Inc.).

Shen, J.B. (1998): 'Designer Corn: Transgenic Corn with Novel Oil Composition (abstract)', *Cereal Foods World*, 43, p. 510.

Souci, S.W., Fuchmann, W., and Kraut, H. (1986): *Food Composition and Nutrition Tables 1986/87*, 3rd rev. ed. (Stuttgart, Wissenschaftliche Verlagsgesellschaft GmbH).

Suzuki, Y., Yasui, T., Matsukura, U., and Terao, J. (1996): 'Oxidative Stability of Bran Lipids from Rice Variety [*Oryza sativa* (L.)] Lacking Lipoxygenase-3 in Seeds', *Journal of Agricultural and Food Chemistry*, 44, pp. 3479-3483.

Tetens, I., Biswas, S.K., Glitso, L.V., Kabir, K.A., Thilsted, S.H., and Choudhury, N.H. (1997): 'Physico-chemical Characteristics as Indicators of Starch Availability from Milled Rice', *Journal of Cereal Science*, 26, pp. 355-361.

Thompson, L.U., Yoon, J.H., Jenkins, D.J.A., Wolever, T.M.S., and Jenkins, A.L. (1984): 'Relationship between Polyphenol Intake and Blood Glucose Response of Normal and Diabetic Individuals', *American Journal of Clinical Nutrition*, 39, pp. 745-751.

Thorne, M.J., Thompson, L.U., and Jenkins, D.J.A. (1983): 'Factors Affecting Starch Digestibility and the Glycemic Response with Special Reference to Legumes', *American Journal of Clinical Nutrition*, 38, pp. 481-488.

Tontisirin, K., Ajmanwra, N., and Valyasevi, A. (1984): 'Long-Term Study on the Adequacy of Usual Thai Weaning Food for Young Children', in *Protein-Energy-Requirement Studies in Developing Countries: Results of International Research*, eds. W.M. Rand, R. Uauy and N.S. Scrimshaw (Tokyo, United Nations University), pp. 265-285.

Tontisirin, K., Thongprasert, K., and Valyasevi, A. (1984): 'Long-Term Evaluation of the Adequacy of habitual Diets to Provide Protein Needs of Adult Thai Men', in *Protein-Energy-Requirement Studies in Developing Countries: Results of International Research*, eds. W.M. Rand, R. Uauy and N.S. Scrimshaw (Tokyo, United Nations University), pp. 126-138.

Torún, B., Cabrera-Santiago, M.I., and Viteri, F.E. (1981): 'Protein Requirements of Pre-school Children: Milk and Soybean Protein Isolate', in *Protein-Energy Requirements of Developing Countries: Evaluation of New Data*, eds. B. Torún, V.R. Young and W.M. Rand (Tokyo, United Nations University), pp. 182-190.

Torún, B., and Viteri, F.E. (1981): 'Energy Requirements of Pre-school Children and Effects of Varying Energy Intakes on Protein Metabolism', in *Protein-Energy Requirements of Developing Countries: Evaluation of New Data*, eds. B. Torún, V.R. Young and W.M. Rand (Tokyo, United Nations University), pp. 229-241.

Tsou, S.C.S., and Hong, T.L. (1989): 'Digestibility of Sweet Potato Starch', in *Improvement of Sweet Potato (Ipomoea batatas) in Asia, Workshop, Trivandur, India, 24-28 Oct. 1988* (Lima, Peru, International Potato Center), pp. 127-136.

Tsuno Foods and Rice (1998): *First International Symposium on Disease Prevention by IP_6 and Other Rice Components, Kyoto, June 8-9, 1998*, Abstracts. (Ito-gun Wakayama, Japan, Tsuno Foods and Rice), 116 pp.

Valdez, D.F., Mallillin, A.C., Cruz, E.M., Kuizon, M.D., and Cabrera, M.I.Z. (1996): 'Iron Absorption from FVRice-Iron Fortified', *Philippine Journal of Science*, 125, pp. 291-299.

Viswanathan, M., Snehalatha, C., Ramachandran, A., Mohan, V., Revathy, M., Paul, S., Lowe, P., Indira, P., and Kymal, P.K. (1988): 'Glycaemic and Insulin Responses to Some Breakfast Items in Diabetic Subjects', *Nutrition Reports International*, 37, pp. 409-418.

USDA (1998): *USDA Nutrient Database for Standard Reference, Release 12*, (Riverdale, MD, USA, Nutrient Data Laboratory, Beltsville Human Nutrition Research Center).

WCRF/AICR (1997): *Food, Nutrition and the Prevention of Cancer: a Global Perspective*. Summary (Washington, D.C., American Institute for Cancer Research/World Cancer Research Fund).

WHO (1985): *Energy and Protein Requirements, Report of a Joint FAO/WHO/UNU Expert Consultation* (Geneva, World Health Organization Technical Report Series 724).

Wolever, T.M.S., Jenkins, D.J.A., Kalmusky, J., Jenkins, A., Giordano, C., Giudici, S., Josse, R.G., and Wong, G.S. (1986): 'Comparison of Regular and Parboiled Rices: Explanation of Discrepancies between Reported Glycemic Responses to Rice', *Nutrition Research*, 6, pp. 349-357.

Yanez, E., Uauy, R., Ballester, D., Parrera, G., Chavez, N., Guzman, E., Saitua, M.T., and Zacarias, I. (1982): 'Capacity of the Chilean Mixed Diet to Meet the Protein and Energy Requirements of Young Adult Males', *British Journal of Nutrition*, 47, pp. 1-10.

Young, V.R., Bier, D.M., and Pellett, P.L. (1989): 'A Theoretical Basis for Increasing Current Estimates of the Amino Acids Requirements in Adult Man, with Experimental Support', *American Journal of Clinical Nutrition*, 50, pp. 80-92.

Yue, P., and Waring, S. (1998): 'Resistant Starch in Food Applications', *Cereal Foods World*, 43, pp. 691-695.

PROSPECTIVE CONTRIBUTIONS FROM BIOTECHNOLOGY INNOVATIONS

RALPH RILEY

Before talking about future technologies I will rehearse some of the ways in which crop production has been increased in the recent past. I draw my data from Nikos Alexandratos (1995) of FAO, and will take as examples wheat and rice in developing countries. In the year 1969-71, 67 million metric tons of wheat were produced compared with 132 million tons in 1988-90. For rice the comparable data show 177 metric tons produced in 1969-71 and 303 tons in 1988-90. There was therefore an annual increment of 3.8% in the production of wheat and of 3.0% in rice harvested. This increased production was obtained from annual increases in the area harvested of 0.9% for wheat and 0.8% for rice. Consequently the increased productivity cannot be primarily ascribed to the more land being cultivated. By contrast if we look at yields in the case of wheat it was 1150 kg/ha in 1969-70 and 1900 kg/ha in 1988-90 – an annual increase of 2.8%. Similarly for paddy rice there was a yield of 1855 kg/ha in 1969-70 and 2775 kg/ha in 1988-90 which amounts to an annual increment of 2.3%. These data demonstrate that growth in production over this period is to be ascribed principally to the deployment of new technology.

The technologies employed included more relevant cultivation practices, better water control, the reduction of losses from diseases, pests and weeds, and the more accurate employment of agro-chemicals. However, the technology making the most important contributions to these factors, as well as others, came from the employment of improved crop genotypes provided by plant breeders. Breeders have always been attempting to improve the yield potential of the crop. Much attention has been concentrated on attempts to reduce or cancel the consequences of factors limiting production, such as diseases and pests or deleterious physical conditions such as extremes of climate or unfavourable soils.

My subject is biotechnology but before I go on to concentrate on that perhaps I should mention work that aims at increasing crop yield potential since we must all ask that production for the next century is increased by whatever means. Two workers, Gurdev Khush of IRRI on rice and Sanjaya Rajaram of CIMMYT on wheat, have undertaken physiological and morphological modelling to devise new structures of their crops with the potential to attain 20% or more yield than at present. There seems every prospect that *the new plant types* that they are devising will succeed in what is essentially tradition breeding, but biotechnology cannot turn up its nose at this, certainly the poor producers and consumers of Asia, Africa and Latin America will not.

But now to what biotechnology can do. There are numerous accounts of what biotechnology can do but here I simply draw your attention to that of P.J. Dart (1990) which will lead the reader into the technologies and the literature. Perhaps the most promising recent innovation has come from genomics, the discipline that describes the structure of the genome. Workers on several crops have been mapping the genomes to provide markers in order to track useful genes in breeding programmes. Very often they would exchange probes (usually cDNA) to assist each other progress their maps. Unexpectedly it transpired that the probes often mapped in the same order in different species. The result of this joint work of several groups (Gale and Devos, 1998; Sasaki, 1998; Bennetzen *et al.*, 1998), enable revelation of the collinearity of the genomes of grass species which extends to oats, barley, wheat, rye, maize, sorghum, rice, millet and also to non-cereal species like sugar cane and Aegilops. This covers species with nuclear DNA contents ranging from 400 Mb to 6000 Mb, many of which have been separated by 60 million years of evolution. The practical consequences of this for plant breeding is that it is possible to search for genes of practical value to agriculture in rice which has the smallest genome size in the cereals and having detected it there the breeder will know where to look for it in wheat. What this amounts to is that all the cereal species can be regarded as a single genetic entity. Although they are not usually inter-fertile (although it makes more comprehensible the discovery in my lab some years ago that wheat can be successfully pollinated by maize), it is to be expected that they will transpose genes to each other without major obstacle.

This will become more important when we have identified the genes that contribute to the increase of yield potential, like those that make hybrid rice so important in China.

I will now turn to genetic limitations that can be applied to factors that limit the attainment of the full yield potential. Perhaps the most promising scheme currently being tested involves the creation of rice forms into which genes have been transposed from viruses. In the virus these genes code for the protein that forms the coat of the virus. The expectation is that the expression of the coat protein gene will cause the plant to be resistant to any subsequent infection by the virus. This would be analogous to the resistance acquired by plants that have previously had a mild viral infection (Beachy, 1990).

In other areas of disease and pest resistance, genes for *resistance* have been sequenced in host plants as have *avirulence* genes from pathogens (bacteria). This has created understanding of the ways in which the two components of the system interact. The resistance gene is triggered by a virulence gene in a pathogen or pest to produce a cascade of products from other genes that counter the invasive attack. Work is ongoing to enhance the production of the range of substances that interfere with the growth of the invader.

Much of what I have discussed above shows ways in which the biotechnology that is already used in crop improvement can be developed further. But I cannot close without showing how biotechnology is already routine. Clive James, of ISAAA, reports that in 1998 there were transgenic crops grown on 20.5 million ha in the USA, 4.3 million ha in Argentina, 2.8 million in Canada, 0.1 million ha in Australia. Of the 27.8 million ha grown world wide 16% were grown in developing countries (principally in Argentina, Mexico and South Africa). It is encouraging that modern methods of food production are already finding their way into developing countries (even if slowly as yet).

REFERENCES

Alexandros, N. (1995): *World Agriculture: Towards 2010, an FAO Study* (FAO, Rome), p. 169.

Beachy, R.N. (1990): 'Plant Transformation to Confer Resistance Against Virus Infection', in *Gene Manipulation in Plant Iprovement*, ed. J.P. Gustafson (Plenum Press, New York), pp. 305-313.

Bennetze, J.L. *et al.* (1998): 'Grass Genomes, *Proc. Natl. Acad. Sci. USA*, 95, pp. 195-1978.

Dart, P.J. (1990): 'Plant Production', in *Agricultural Biotechnology Opportunities for International Development*, ed. G.J. Persley (CAB Inter., Wallingford, UK).

Gale, M.D., and Devos, K.M. (1998): 'Comparative Genetics in the Grasses', *Proc. Natl. Acad. Sci. USA*, 95, pp. 1971-1974.

Sasaki, T. (1998): 'The Rice Genome Project in Japan', *Proc. Natl. Acad. Sci. USA*, 95, pp. 2027-2028.

PROSPECTS OF ECONOMIC RETURNS FROM INVESTMENTS IN AGRICULTURAL RESEARCH

ROBERT E. EVENSON

More than four decades have passed since the first studies of the economic impact of agricultural research and extension were reported. Today, a complex system of International Agricultural Research Centers (IARCs), National Agricultural Research Systems (NARS) and sub-national or regional programs has been built covering most of the globe.[1] Similarly, agricultural extension programs have been developed in most countries. These programs are under various forms of review and evaluation, as is appropriate given their perceived importance as public sector investments. Some of these evaluations are administrative or financial, others are informal "peer" reviews and ratings. Some reviews are economic impact evaluations and these are the concern of this paper.

The study of hybrid corn development by Zvi Griliches in 1957 is now regarded as the pioneering study in the field. A recent review of the studies reporting economic impact calculations for agricultural research and extension programs covered more than 200 studies and more than 400 estimates of returns to investment in agricultural research and extension programs (Evenson, 2000).

Economic impact evaluations differ from other evaluations in that they associate economic benefits produced by a program with the economic costs of the program. This literally means computing a benefit/cost ratio and/or other associated economic calculation, such as the present value of benefits net of costs, or internal rates of return to investment.[2]

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[1] See Boyce and Evenson (1978); Judd *et al.* (1986); and Pardey and Roseboom (1993) for international reviews of investment in research and extension.

[2] Many of these evaluations also undertake growth accounting.

In this paper, I will attempt to draw lessons for future investment policy and for prospects for food production from this body of studies. In part I of the paper I discuss studies of agricultural extension. In part II, I discuss studies of public sector agricultural research. In part III studies of industrial R&D impacts on agriculture are reviewed. *Ex Ante* studies are reviewed in part IV. A summary is developed in part V. In part VI, I develop projections of food supply for the year 2020 based on these studies and consider alternative scenarios.

1. Studies of Agricultural Extension Impacts

Extension programs seek two general objectives. The first is to provide technical education services to farmers through demonstrations, lectures, contact farmers and other media. The second is to function in an interactive fashion with the suppliers of new technology, by providing "feedback" to technology suppliers and technical information to farmers to enable them to better evaluate potentially useful new technology and ultimately to adopt (and adapt) new technology in their production systems. In some institutional settings extension programs compensate for poor education, communication and markets. In more advanced settings, extension programs facilitate adoption of recently developed technology.

Studies of agricultural extension impacts can be grouped into three categories:

A) Statistical studies based on farm level (cross-section) observations where extension services vary by observation but it is presumed that technology or research services do not vary by observation.

B) Statistical studies based on aggregated farm production data (e.g. a district, country or state) usually in a reported cross-section framework, where both extension and applied research services are specified to vary by observation (and where research variables are included along with extension variables).

C) Statistical studies based on aggregated farm data (usually reported cross-section) where for reasons of data availability a variable measuring the combined services of research and extension is constructed.

These studies are summarized in table 1. The summary statistic provided is the internal rate of return (IRR) calculated in the studies reviewed. Several farm observation studies used an index of extension staff-farm contact either in visits to the farm by extension staff or in farmer visits to extension meetings or demonstrations. Birkhauser *et al.* 1991, among others,

Table 1. *IRR Estimates Summary.*

	Number of IRRs Reported	Percent Distribution						Approx Median IRR
		0-20	21-40	41-60	61-80	81-100	100+	
Extension								
Farm Observations	16	.56	0	.06	.06	.25	.06	18
Aggregate Observations	29	.24	.14	.07	0	.27	.27	80
Combined Research and Extension	36	.14	.42	.28	.03	.08	.06	37
By Region								
OECD	19	.11	.31	.16	0	.11	.16	50
Asia	21	.24	.19	.19	.14	.09	.14	47
Latin America	23	.13	.26	.34	.08	.08	.09	46
Africa	10	.40	.30	.20	.10	0	0	27
All Extension	81	.26	.23	.16	.03	.19	.13	41
Applied Research								
Project Evaluation	121	.25	.31	.14	.18	.06	.07	40
Statistical	254	.14	.20	.23	.12	.10	.20	50
Aggregate Programs	123	.16	.27	.29	.10	.09	.09	45
Commodity Programs								
Wheat	30	.30	.13	.17	.10	.13	.17	51
Rice	48	.08	.23	.19	.27	.08	.14	60
Maize	25	.12	.28	.12	.16	.08	.24	56
Other Cereals	27	.26	.15	.30	.11	.07	.11	47
Fruits and vegetables	34	.18	.18	.09	.15	.09	.32	67
All Crops	207	.19	.19	.14	.16	.10	.21	58
Forest Products	13	.23	.31	.68	.16	0	.23	37
Livestock	32	.21	.31	.25	.09	.03	.09	36
By Region								
OECD	146	.15	.35	.21	.10	.07	.11	40
Asia	120	.08	.18	.21	.15	.11	.26	67
Latin America	80	.15	.29	.29	.15	.07	.06	47
Africa	44	.27	.27	.18	.11	.11	.05	37
All Applied Research	375	.18	.23	.20	.14	.08	.16	49
Pre-Technology Science	12	0	.17	.33	.17	.17	.17	60
Private Sector R&D	11	.18	.09	.45	.09	.18	0	50
Ex Ante Research	83	.11	.36	.16	.07	.01	.05	44

have noted that this variable is subject to endogeneity bias. This is because at least some of the contacts are farmer initiated. If one observes that more efficient farms have more extension contact one cannot conclude that extension contact caused the efficiency difference. It may simply reflect the demand for information by the more efficient farmers.

A second form of endogeneity bias in farm specific extension variables may be due to extension staff selectivity (i.e. the staff contact the best farmers more frequently). The remedy for this problem is to use a statistical procedure to deal with it (instrumental variables or 2SLS, 3SLS in a structural model). Only four of the studies covered in table 1 utilized this remedy. These four studies did find statistically significant extension impacts.

A number of extension studies addressed the endogeneity problem with the extension variable by creating variables measuring "extension services supplied". For some studies this variable took the form of a dummy variable indicating whether a community had extension services supplied to it. For others it was a measure of services supplied per farm or per unit of land area for a defined extension region. These variables were not farm specific, but were assigned to each farm observation in the extension region. These studies reported relatively high rates of return to investment.

Several studies were based on aggregated data. In some cases the data were district or state averages compiled from Census of Agriculture data. In other cases production and input data from different sources reported for the district and state level were utilized. One study was international. All of these studies included both research and extension variables and in some cases schooling variables as well.

Most of the studies reported "rate of return" calculations. These are "marginal" rates of return since they are based on coefficients estimated for the extension variable (sometimes interacted with other variables). The rate of return was typically calculated by simulating a one dollar increase in extension expenditure in time t, then calculating the change in the extension variable in subsequent periods from this investment utilizing the time weights incorporated in the extension variable. The estimated coefficient for the extension variable then enables one to construct the "benefits stream" associated with the investment (multiplying by the units affected) and the internal rate of return, IRR, is calculated from this.

These estimated rates of return suggest a broad range of economic impacts ranging from negligible impacts to very high impacts. Table 1 also summarizes studies where the technology variable was based on combined extension and research data. These estimated rates of return also range from modest to very high. They will be discussed further in the next section.

2. STUDIES OF APPLIED AGRICULTURAL RESEARCH (PUBLIC SECTOR)

The studies summarized in the Applied Research section constitute the major evidence for economic impacts through technology. These studies can be categorized into two groups. The first group of studies adopted a "project evaluation" approach.[3] The second group adopted a statistical estimation approach. This entailed the construction of a research services variable(s) and the direct estimation of a coefficient(s) for this variable. Economic impacts in the form of (marginal) internal rates of return were computed and reported in the studies reviewed.

2.1. *The Project Evaluation Studies*

The term project evaluation is used here to refer to the use of methods relying on evidence from different sources to measure economic impact.

All methods should, in principle, address locational and timing dimensions. For project evaluation studies these dimensions are generally inherent in the project setup. One of the first and most important studies of this type was the hybrid corn study by Griliches (1957). Griliches did not treat the development of a single variety of hybrid corn variety or even the set of varieties released in Iowa as the project being evaluated. He recognized that the project encompassed the pre-technology science (PTS) entailed in inventing a method of inventing (i.e., the hybridization methodology) and covered applied agricultural research (plant breeding) in both public and private R&D programs.

Griliches also recognized spillover barriers. The pattern of adoption of hybrid corn varieties varied by state because of high degrees of locational specificity of hybrid corn varieties. Alabama, for example, did not adopt hybrid corn varieties until applied hybrid corn breeding programs were developed in Alabama, targeting varieties to the soil and climate conditions in Alabama.

The Griliches study set forth the basics of the measurement of benefits. Hybrid corn varieties, when adopted, reduce marginal and average costs, and shift the supply curve to the right (which in competition is the summation of the marginal costs of farmers above the minimum point on the average variable cost curves). Economic benefits are the change in consumer's and producer's surpluses and are measured by the area under the demand curve between the original supply curve and the shifted supply curve.

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[3] Other reviewers describe these studies as using an "economic surplus" methodology. This is not very satisfactory since all studies are attempting to calculate economic surplus benefits.

Griliches noted that this area is well approximated by the change in average variable costs times the original quantity produced when the supply curve shift is parallel.[4]

Griliches used farm experimental data in a with-without design to measure the average variable cost shift associated with hybrid varieties.[5] With information on adoption rates and the size of the shift, a benefit stream from 1900 to 1957 was created. A cost stream (including both public sector and private firm costs) was also estimated. Griliches then performed the standard investment calculations to compute the present value of benefits and costs in 1957:

$$\mathrm{PVB}_{57} = \sum_{t=1900}^{1900} b_{t\_}(1.05)^{t-1900}$$

$$\mathrm{PVC}_{57} = \sum_{t=1900}^{1957} c_{t\_}(1.05)^{t-1900}$$

Griliches then computed the following ratio:

$$\frac{\mathrm{PVB}_{57} \times .05 + b_{57}}{\mathrm{PVC}_{57} \times .05 + c_{57}}$$

This procedure converted the cumulated present values to flows and under the assumption that 1957 benefits (b_{57}) and costs (c_{57}) would continue indefinitely, this ratio was interpreted as a "dollars benefit per dollar cost" ratio. The ratio (approximately 7) was sometimes interpreted as a 700 percent rate of return on investment. Griliches himself later noted that it should be interpreted as a modified benefit-cost ratio not as a rate of return (Griliches, 1991). He also computed the internal rate of return for the program (the rate of discount at which $\mathrm{PVB}_{57} = \mathrm{PVC}_{57}$) to be approximately 44 percent.

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[4] Lindner and Jarrett (1976) discuss cases where the supply curve shift is not parallel. There is little evidence that supply curve shifts have a convergence pattern. There is some evidence (see Evenson and Huffman (1994)) for technology-induced increases in farm size. This would be consistent with divergent supply curve shifts. Huffman and Evenson (1993) note that different magnitudes of shifts for farms of different sizes (e.g., large farms realizing shifts, while small farms do not) do not produce non-parallel supply curve shifts.

[5] This shift was estimated to be 28 percent. Many non-economists contend that new technology must have a significant cost advantage (e.g. doubling) before it is adopted. Most careful studies show that this is not the case.

Some of the project evaluation studies summarized in table 1 actually used statistical evidence. Some were based on time-series data only. Others used repeated cross-section data. Several of the commodity studies summarized in table 1, also used project evaluation methods.

The 60-plus studies based on project evaluation methods reported 121 IRRs. Almost all of these are high to very high (Many studies reported a range of IRRs, Evenson, 2000).

2.2. *Studies Based on Research Variable Coefficient Estimates*

In table 1 a summary of roughly 120 studies reporting 254 IRRs utilized statistical estimates. All of these studies are based on aggregate data. Most are based on repeated cross-section. A broad range of countries and commodities are studied and most IRRs are in the high to very high range.[6]

A number of studies reported IRRs for aggregate (many commodities) research programs. These IRRs were comparable to those reported in single commondity studies indicating broad inputs.

Virtually all studies summarized in tables 1 reported statistical significance for coefficient estimates of the research variable utilized.

3. STUDIES OF INDUSTRIAL R&D SPILL-IN AND PRE-TECHNOLOGY SCIENCE SPILL-IN

Surveys of research expenditure in recent years have identified considerable industrial R&D directed toward products sold to and used in the agricultural sector. Agricultural machinery and agricultural chemicals are obvious cases where industrial R&D is directed toward the improvement of agricultural inputs. Johnson and Evenson (1997) report estimates of patented inventions manufactured in a number of industries that are used in the agricultural sector.

Table 1 summarizes several studies incorporating industrial R&D variables. The social (private plus spillover) rate of return to this industrial R&D is roughly equal to the social rate of return to public agricultural research.

Another type of spill-in that is recognized in few studies is the "recharge" spill-in from pre-technology science. Many of the studies summarized in table 1 actually covered a wide range of research program activities including many pre-technology science activities. Twelve summarized

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[6] The studies summarized in table 1 where research and extension expenditure data are amalgamated into a single variable are comparable to the applied research studies.

in table 1 specifically identified PTS expenditures and activities. It may be noted that these studies report the highest rates of return.

4. *Ex Ante* Studies

Research and extension programs in either public or private sector organizations require both design and resource allocation decisions. The project evaluation framework has been applied to many research and extension investment decisions. The World Bank and other lending or granting agencies require what is in effect *ex ante* impact evaluation studies as an integral part of the lending process. Yet, it is probably fair to say that *ex ante* studies of research and extension lack credibility in these agencies.[7]

Interestingly, as noted in the next section, the rates of return computed for *ex ante* studies have less variability than those for *ex post* studies. They also have a lower mean and median.

5. A Summary of IRRs

IRRs for both extension and research studies are summarized in table 1; distributions of IRRs for a number of study categories are presented and median IRRs are also reported. Two features characterize virtually every category. The first is that the IRRs are high. Seventy-four percent of the extension IRRs and 82 percent of the research IRRs exceed 20 percent. The second feature of the IRRs is that the range of estimates is broad. Every category (except for private sector R&D spillovers) includes studies reporting both low IRRs and high IRRs. Interestingly the category showing the narrowest range of IRRs is the *ex ante* study category.

Given the breadth of the range of IRRs in each category, it is difficult to draw strong conclusions regarding differences in means between cate-

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[7] The World Bank's recent OED study of agricultural research and extension did call for higher standards of *ex ante* evaluation of extension projects (and of research projects as well) but did not attempt the *ex post-ex ante* comparisons required to give credibility to *ex ante* studies. It chose to stress informal *ex post* ratings of projects and was critical of existing *ex post* economic impact studies. The OED study was primarily concerned with the management and design issues associated with extension. It reached the conclusion that the Bank's T&V management focus was not the most effective management style for extension, although it is difficult to find the basis for this conclusion in the report. The *ex post* studies (see tables 1 and 2) which concluded that T&V managed extension programs did have an economic impact, but were less conclusive as to whether the T&V management style was more productive than alternatives, were criticized in the report.

gories. It can be noted, however, that the categories with the greatest proportions exceeding 40 percent are pre-technology science, private sector R&D, rice research, and fruits and vegetables research. Research studies have higher proportions exceeding 40 percent (59 percent) than is the case for extension studies (51 percent). Studies of commodity research programs have a higher proportion exceeding 40 percent (62 percent) than studies of aggregate research programs (57 percent).

Regional distributions vary with studies of both research and extension in Africa and have lower proportions exceeding 40 percent than in other regions. Asian research IRRs are especially high.

Actually as noted above, some of the very high IRRs are "suspect" in that they could be inconsistent with actual economic growth experience. It is of interest to note that the proportion of very high (exceeding 80 percent) IRRs is highest for statistical commodity research studies where spending ratios are lowest (and where one may well be understating real research expenditure as well). Typically, for commodity programs even in developed countries, research/commodity value ratios are well below one percent. This is particularly true in Asia where the highest proportion of very high IRRs are reported.

Studies of industrial R&D indicate that the private IRRs captured by firms are generally similar to IRRs for other investments made by the firm. These studies also show considerable spill-overs and indicate that the social rate of return is considerably higher than the private rate of return.

6. Implications for Future Food Production

The International Model for Policy Analysis of Agricultural Commodities (IMPACT) of the International Food Policy Research Institute (IFPRI) is one of several models used to project food production over future years. This model is based in part on the IRB estimates summarized in table 1. (see Ageroli, *et al.*, 1993 and the Appendix for details).

The IMPACT model is a computable equilibrium market model for agricultural products-crops and livestock (17 commodities). It is based on 35 country-region sub-models (see Agcaoili *et al.*, 1993, for more details). Each sub-model consists of equations depicting the supply for each commodity as a function of price and non-price terms. The demand for each commodity is also described as a function of price, income, population and non-price terms. The sub-models are linked through trade, which may be free or restricted by tariffs. The model solves for global and sub-model equilibrium prices for each commodity where all markets are cleared.

The *endogenous* variables determined by the model equilibrium are:

1) Commodity prices and quantities by country-region.
2) Trade quantities (imports and exports) by country-region.
3) Cropped area by commodity by country-region.
4) Commodities consumed-calories per capita-percent children malnourished by country-region.

The model also generates the per capita calorie availability from food consumed using standard kilocalorie conversion values for different foods. Estimates of the relationship between the percentage of children 0-6 malnourished as a function of calorie availability are made from pooled cross-section, time and series data for 61 developing countries for 1980, 1985 and 1990. (World Nutrition Database ACC-SCN, 1992).

The *exogenous* variables in the model are:

1) Population by year, by country-region.
2) Non-agricultural income by year, by country-region (agricultural incomes are endogenous).
3) Total land area by country-region.
4) Non-price (productivity) supply growth including contributions from:
    a) Farmers schooling;
    b) Agricultural extension;
    c) Public sector agricultural research;
    d) Private sector agricultural research.

The non-price supply component for both area and yield is specified as an annual rate of change. This trend can be interpreted as a total factor productivity growth trend. Productivity growth is traceable to several sources. These include improvements in the human capital (schooling) of farmers, agricultural extension programs, and agricultural research programs (public and private), all of which produce positive productivity gains.

The IFPRI-IMPACT model is not based on trend estimates or judgements except to achieve continuity with the recent past. It relies instead on a combination of a detailed *ex ante* research study for rice production and the extensive body of *ex post* rate of return studies reviewed in this paper.

The *ex ante* rice research study on which the rice productivity projections were made is discussed in Evenson, *et al.*, 1986. Other productivity components are discussed as well. The Appendix also discusses the use of rate of return estimates to "scale" other commodity-region projections to the rice projections using median IRRs.

The baseline case in the IFPRI-IMPACT model is based on continued support of the research and extension programs at present levels. Biotechnology contributions are expected to come on line first for rice then other commodities according to scientists' expectations. Industrialization and trade liberalization are expected to continue.

The following alternative policy scenarios are considered:

A. Demographic Gift;
B. Delayed Industrialization;
C. Reduced IARC-NARS Support;
D. A Ten-Year Biotechnology Delay;
E. Climate Change.

6.1. *Demographic Gift*

The Base Case population scenario is based on the U.N. "Medium" population projection. The demographic gift projection reduces this to the U.N. "Low" projection. This is consistent with the demographic gift (Bloom and Williamson, 1998) associated with reduced population growth. The labor force growth contributing to production will not be reduced until after the time lag between birth and labor force entry occurs. Thus in the period from 1990 (1998) to 2020, labor force will grow at the medium projection but the number of pre-labor force consumers will decline. This is a one-time "gift" in the sense that the ratio of laborers to population will rise only for a short period before it returns to normal as labor force growth slows.

6.2. *Delayed Industrialization*

Another realistic scenario is that of delayed industrialization reforms. The past ten to fifteen years have seen considerable progress by a substantial number of developing economies in improving trade and industrialization policy. But this move toward industrialization and the rapid growth associated with it can be reversed and delayed. This may come about because of increased local conflicts. (By and large, countries with significant civil strife do not make economic progress.) The recent crisis in Asia demonstrates this effectively. This scenario is one where the ITI class standings for 1995-2000 are maintained through subsequent periods.

6.3. *Reduced IARC-NARS Support*

A substantial shift in international support in terms of loans or grants for National Agricultural Research Systems (NARS) and International Agricultural Research Centers (IARCs) over recent decades has taken place. In the 1950s, 1960s, and 1970s, bilateral aid agencies supported NARS building programs and extension programs. U.N. agencies did as well. Today these agencies support little research. For practical purposes, support for NARS and most extension programs is provided by the World Bank (and other banks and bilateral programs to a lesser extent).

6.4. *Ten-Year Biotechnology Delay (Developing Countries)*

The contributions of biotechnology have been built into the non-price terms according to the timing indicated in the scientist survey. For rice these contributions begin early next century and become quite significant by 2015. For other crops the timing is delayed. The biotechnology delay scenario delays the biotechnology contribution by ten years for developing countries. We are presuming that the anti-biotechnology movement will have little or no effect on developed countries, but it could easily delay access to biotechnology in most developing countries. The absence of strong intellectual property rights will also delay access to the "genes for sale" already being made available in developed countries. This scenario is supported by some NGO groups (Altieri, 1997).

6.5. *Climate Change*

A number of projections of climate change have been made in recent years. Agreement on the timing and extent of this change has not been reached. The estimates used here are that mean temperatures will rise by 1 degree Celsius by the year 2020 and that rainfall will increase by 3.5 percent.

Three recent studies have provided estimates of the effects of climate change on agricultural production. The first, by Mendelsohn, Nordhaus and Shaw (1994) pioneered the use of the "Ricardian" method for relating climate change to productivity through land values. This study for the U.S. showed that agricultural productivity in the Northern counties in the U.S. would generally experience increased productivity from climate change, while the warmer Southern counties would experience losses.

A second study for Brazil (Sanghi *et al.*, 1997) found similar effects in Brazil. Municipios in the South experienced gains, Municipios in the warmer North and Central regions experienced losses. A third study for India (McKinsey, 1998) found similar effects.

The three studies were sufficiently consistent in terms of fitting into a global "surface" that we believe that extrapolations to other countries (based primarily on latitude) are justified. These are the basis for the Climate Change scenarios (the reader should apply caution, given the limited data on which the scenarios are based).

The Base Case 2020/1990 ratios for Production, Area, Trade and Prices are summarized by commodity in table 2. 2020/1990 price ratios are reported for the four policy scenarios plus a "worst case" scenario.

The Base case production scenarios show that global crop production will increase by approximately 60 percent by 2020. Area planted to crops will expand by roughly 10 percent. (This includes multiple cropping so area in crops will expand by roughly 5 percent [mostly in Africa – see below]). Most production gains will come from yield gains. These yield gains are roughly similar to the post-Green Revolution period gains.

Animal production will increase by more than crop production and most of this will be due to increased animal units. For beef this indicates a significant increase in pasture land.

World trade will increase for all commodities and this will take the form of increased exports by developed countries and increased imports by developing countries.

Base case price projections indicate continued declines in world prices for all commodities. These projected declines are highest for rice and other grains.

Table 2 also includes four policy scenarios for price ratios and these can be directly compared to the base case price scenario.

The first is the "Demographic Gift" scenario. This scenario has large price effects (note that it is temporary and would hold only for this period). Because of reduced demand (number of consumers) prices will fall further than base case prices for all commodities.

Delayed industrialization, on the other hand, will mean that prices will be higher than in the base case (by roughly 5 to 6 percent). This is due to reduced private sector R&D spillovers to agriculture.

Reduced IARC-NARS support will have a larger impact on prices than delayed industrialization. Prices will be roughly 10 to 15 percent higher than in the base case.

Delayed biotechnology for developing countries also has significant price effects. These are similar to the reduced IARC-NARS support effects for crops but are smaller in magnitude than for livestock products.

Global climate change effects are quite small (but see local effects below). Price effects are only one or two percent above the base case.

The "worst case" calculation is the sum of the delayed industrialization, reduced IARC-NARS, delayed biotechnology and climate change effects. In this worst case, prices of most crops will rise over the 1990 levels but not sufficiently to qualify as a "World Food Crisis".

Global effects however, are really quite misleading for policy analysis as tables 3 and 4 show. In table 3 base case growth rates for the 1993-2020

Table 2. *Global Base Case and Policy Scenarios by Commodity.*

Commodity	Base Case 2020/1990 Ratios				Policy-Price 2020/1990 Ratios					
	Production	Area	Trade	Prices	Demographic Gift	Delayed Industrialization	IARC phaseout	Delayed Biotechnology	Global Warming	Worst Case
Wheat	1.58	1.06	1.62	.85	.68	.90	.96	.94	.86	1.16
Maize	1.56	1.13	1.36	.77	.62	.81	.85	.90	.78	1.03
Rice	1.66	1.07	1.70	.80	.62	.86	.95	.96	.81	1.17
Other Grains	1.48	1.09	1.60	.75	.63	.81	.85	.82	.75	1.04
Soybeans	1.77	1.14	2.20	.90	.84	.91	.91	.92	.91	.98
Roots/Tubers	3.28	1.15	1.30	.82	.66	.86	.93	.95	.84	1.09
Beef	1.53	1.35	2.87	.94	.85	1.01	1.00	.95	.95	1.31
Pork	1.83	1.53	1.64	.90	.83	1.04	1.06	.91	.91	1.38
Mutton	1.98	1.36	1.84	.96	.89	.99	1.02	.97	.98	1.13
Poultry	1.80	1.53	3.27	.90	.83	.92	.94	.91	.90	1.01
Eggs	1.92	1.06	5.81	.75	.68	.75	.75	.76	.75	.75
Milk	1.53	1.15	3.60	.93	.83	.93	.93	.93	.93	.93

Table 3. *Base Case – All Cereals.*

Countries/Regions	Growth Rates (%) 1993-2020					
	Area/No.	Yield	Production	Demand	Food	Feed
USA	0.12	0.96	1.08	0.81	0.64	0.84
EC and O W Europe	0.04	0.42	0.46	0.39	0.10	0.53
Japan	-0.49	-0.03	-0.52	0.29	-0.05	0.62
Australia	0.12	1.75	1.88	1.01	0.84	1.07
Other Developed	0.07	1.09	1.16	1.07	1.16	0.99
E Europe	0.09	1.02	1.11	0.24	-0.19	0.43
CIS (former USSR)	0.04	1.18	1.22	0.49	-0.06	0.73
Latin America	0.44	1.37	1.82	1.63	1.35	1.92
Nigeria	1.20	1.35	2.56	2.85	2.92	2.11
Northern SSA	0.99	1.55	2.56	3.14	3.15	2.27
Central-West SSA	1.38	1.77	3.18	3.06	3.08	2.65
Southern SSA	1.19	2.26	3.48	2.87	2.90	2.21
Eastern SSA	1.25	1.77	3.05	2.86	2.90	2.28
Sub-Saharan Africa	1.17	1.67	2.86	2.96	3.00	2.25
WANA	0.11	1.85	1.96	1.97	1.94	2.12
India	0.07	1.42	1.49	1.53	1.48	3.04
Pakistan	0.19	1.54	1.73	2.92	2.92	2.96
Bangladesh	0.02	1.36	1.39	1.65	1.65	2.41
Other S. Asia	0.12	1.72	1.84	2.73	2.74	2.61
Indonesia	0.09	0.98	1.07	1.44	1.18	3.34
Thailand	-0.07	1.00	0.93	1.39	0.45	2.77
Malaysia	-0.04	1.00	0.95	2.22	1.96	2.48
Philippines	0.10	2.06	2.17	2.26	1.88	3.00
Vietnam	0.00	1.41	1.41	1.43	1.41	2.29
Myanmar	0.35	1.58	1.93	1.39	1.37	2.62
Other SE Asia	0.14	2.22	2.37	2.14	2.14	2.07
China	0.02	0.98	1.00	1.32	0.58	3.22
Other E. Asia	-0.47	0.84	0.36	1.57	0.67	2.49
South Asia	0.08	1.43	1.51	1.76	1.72	2.99
South Asia (ex India)	0.11	1.50	1.61	2.42	2.42	2.88
Southeast Asia	0.08	1.30	1.38	1.61	1.34	2.94
East Asia	0.00	0.98	0.98	1.34	0.59	3.13
Asia	0.05	1.16	1.22	1.51	1.14	3.09
Developed	0.06	0.94	1.00	0.57	0.19	0.71
Developing	0.29	1.20	1.49	1.71	1.43	2.63
World	0.20	1.06	1.27	1.27	1.21	1.40

Table 4. *Malnourished Children Simulation (Percent children (0-6) malnourished).*

Countries/ Regions	Base Case			Reduced Research Support		Delayed Industrialization	Global Warming
				IARC NARs	Biotech Delay		
	1990	2010	2020	2020	2020	2020	2020
Latin America	20.40	16.91	14.05	14.47	14.09	14.3	14.05
Nigeria	35.4	30.79	29.52	30.21	29.86	29.89	30.90
N Africa	31.40	29.08	27.93	28.92	28.23	28.48	31.09
C and W Africa	22.70	22.44	21.10	21.62	21.42	21.37	21.23
S Africa	24.80	22.43	21.24	21.83	21.56	21.54	21.21
E Africa	25.50	25.47	24.77	25.35	25.03	25.08	24.81
WANA	13.40	11.56	9.70	10.05	9.68	9.88	9.67
India	63.00	51.25	45.49	46.91	45.70	46.22	45.49
Pakistan	41.60	36.62	32.40	33.35	32.64	32.91	32.38
Bangladesh	65.80	59.20	52.85	58.12	53.86	55.55	53.14
Other S Asia	37.00	31.62	26.59	27.83	26.90	27.22	26.80
Indonesia	14.00	10.05	7.74	8.01	7.85	7.90	7.78
Thailand	13.00	7.32	5.23	5.33	5.26	5.35	5.25
Malaysia	17.60	12.41	9.88	10.05	10.00	10.06	9.91
Philippines	33.60	25.81	21.29	22.66	21.72	22.24	21.43
Other SE Asia	40.00	35.69	32.78	35.21	32.98	34.15	33.11
China	21.80	15.30	13.78	14.26	13.79	14.24	13.78
S Asia	58.50	47.68	41.37	43.03	41.60	42.22	41.40
Developing	34.30	28.01	25.40	26.33	25.83	26.00	25.50

period for cereal crop area, yield, production demand and food and feed demand are projected by country/region. Trade effects are the difference between demand and production. We first note that area expansion is projected to be low in most developing countries (negative in some). Area expansion will be high in most Sub-Saharan African countries because these countries have land on which to expand. This will have biodiversity habitat effects.

Yield projections are actually higher for developing countries than for developed countries reflecting the fact that they have more "catch-up" potential.

Production growth rates exceed demand growth rates for most developed countries (excluding Japan). This means that exports will grow at substantial rates. For most developing countries, demand growth exceeds production growth. Because of large area expansion rates, Sub-Saharan Africa countries will not have large import growth, however.

Table 4 reports effects of an important local welfare index in developing countries, the proportion of children 0-6 who exhibit some degree of malnourishment. First note that this measure shows great variability in 1990 by region. The base case projections show that the percent malnourished will decline from 34 percent in 1990 to 25 percent in 2020 (from 1960 to 1990 it fell from 45 percent to 34 percent). This is a favorable projection although it does vary by region (falling least in East Africa). Clearly, however, in 2020 serious local problems will remain and they form the basis for "local food crises" even if a global food crisis is unlikely to occur. The policy scenarios show that reduced research support, delayed industrialization, delayed biotechnology and climate change will reduce progress in reducing malnutrition. The "global" effects are small, but local effects for some countries, e.g. Bangladesh and Nigeria, are significant.

7. PROSPECTS

The policy scenarios in the IFPRI-IMPACT model are built quite directly on the experience of the past 40 years in the conduct of agricultural research and extension programs. They reflect the extensive "pipelines" in technology production where the effects of research on productivity are often subject to long lags. They also reflect the fact that the building of research (and extension) "capacity or capability" itself implies continuity of research impacts. This is further enhanced by the development of international nursery and related research "networks" which enable plant breeders and other researchers better access to international genetic pools and related science pools.

Many observers note that there are "yield ceilings" that appear to inhibit further research progress in some commodities and locations. These ceilings do exist (e.g. at the IRRI research center), but are sometimes temporary and are not evident in all locations. It may be true that much of the agricultural research gains in tropical and sub-tropical countries over the past four decades could be seen as "catch-up" or "convergence" driven. As these countries approach the technology frontiers of the developed (temperate zone) countries, they will experience diminishing returns. But two observations may be made in this regard.

The first is that many developing countries are still a considerable distance from the yield ceilings and related frontiers of the field. The second is that the yield ceilings and technology frontiers are themselves being changed by the implementation of modern biotechnology methods. The first generation of agricultural biotechnology products is now being marketed. These products are based on "single gene" traits. Later generation products will use marker-aided breeding techniques and multiple gene transformations.

The agricultural sector in most countries of the world has performed remarkably well in responding to the population increase that characterized the second half of the 20th century. The prospects for a continuation of this performance are good.

APPENDIX: THE IFPRI-IMPACT MODEL BASE CASE

The International Model for Policy Analysis of Agricultural Commodities (IMPACT) developed at the International Food Policy Research Institute (IFPRI) is a partial equilibrium model covering 17 commodities and 35 country/regions. It computes global equilibriums in real prices. It is synthetic in that it uses price elasticities and non-price parameters from other studies. The model incorporates non-agricultural sector linkages but does not compute equilibriums for markets other than the 17 commodities.

Each country/region sub-model has a set of equations for supply, demand and prices for each commodity and for intersectoral linkages with the non-agricultural sector. Crop production is determined by area and yield response functions. Area functions include price responses (own and cross-price terms) and a non-price trend reflecting remaining land availability and technology. Yield is a function of the price of commodity and prices of inputs and a non-price total factor productivity (TFP) change term.

Livestock commodities are similarly modeled.

Domestic demand is the sum of food, feed and industrial use demand. Food demand is a function of prices (of all commodities), per capita income and population. Country specific population in growth rates are based on UN projections (World Population Prospects, UN, 1992). Income growth is partially endogenous to the model and agriculture-non-agriculture links are specified. Feed and industrial use demands are derived from final demands.

Prices are endogenously determined. Domestic prices are linked to global equilibrium prices via exchange rates and producer-consumer subsidies and trade restrictions are allowed. Other policy instruments (acreage restrictions) are considered.

Trade is determined by net supply-demand equilibrium conditions.

Malnourished children projections for children (0-6) are based on weight-for-age standards set by the U.S. National Center for Health Statistics. Data for 61 developing countries for 1980, 1985 and 1990 (World Nutrition Database, ACC-SCN, 1992) were used to link malnourished children proportions to per-capital calorie consumption (determined in the model).

The non-price (TFP) terms are based on a study of Indian productivity (Evenson *et al.*, 1996), a classification of Industrial Technological Infrastructure (Evenson and Westphal, 1994) and a study of rates of return to agricultural research and extension (Evenson, 2000).

The ITI classification of Evenson and Westphal (1994) included the following classes:

ITI Class	Description
1A:	Traditional ITI. Economics lack basic infrastructure. Government influence limited.
1B:	First emergence. Some direct foreign investment.
1C:	Partial modernization. Agricultural sector well developed. No R&D in producing firms.
2A:	Mastery of conventional technology. Market skills well developed. R&D in firms.
2B:	Transition to modern capacity. Reverse engineering capacity, sciences developed.
2C:	Expert competitiveness (NIC-hood), adaptive invention, IPRs developed.
D:	Developed country capabilities.

Appendix Table A1 reports the ITI projections used in the base case.

Evenson (2000) reviews the rates of return studies utilized in constructing the base case. These rates of returns are summarized in table 1. The relative median IRR ratios for commodities and regions were used to scale non-price terms to the rice base case terms.

REFERENCES

Agcaoili, M.C., Oga, K., and Rosegrant, M.W. (1993): 'Structure and Operation of the International Food Policy and Trade Simulation (IFPTSIM) Model'. Paper presented in the Second Workshop of the Research Project on Projections and Policy Implications of Medium- and Long-Term Rice Supply and Demand (Los Banos, Philippines, IRRI).

Altieri, M.A. (1997): 'The CGIAR and Biotechnology: Can the Renewal Keep the Promise of a Research Agenda for the Rural Poor?'. Paper submitted for consideration by participants of consultation on biotechnology called by CGIAR Chairman, April 18, 1997 in Washington, DC.

Birkhaeuser, D., Evenson, R.E., and Feder, G. (1991): 'The Economic Impact of Agricultural Extension: A Review', *Economic Development and Cultural Change*, 39(3).

Bloom, D.E., and Williamson, J.G. (1998): 'Demographic Transitions and Economic Miracles in Emerging Asia', *The World Bank Economic Review*, 12.

Evenson, R.E., and Boyce, J.K. (1975): 'National and International Agricultural Research and Extension Programs', New York, Agricultural Development Council.

Evenson, R.E. (2000): 'Economic Impact Studies of Agricultural Research and Extension', forthcoming, *Handbook of Agricultural Economics*, G.B. Gardner and G. Rausser (eds.) (Amsterdam, North Holland Press).

Evenson, R.E., and Huffman, W.E. (1993): 'The Effects of R&D on Farm Size, Specialization and Productivity', Chapter 3 in *Industrial Policy for Agriculture in the Global Economy*, S.R. Johnson and S.A. Martin (eds.) (Iowa State University Press, Ames, Iowa).

Evenson, R.E., and Westphal, L. (1994): 'Technological Change and Technology Strategy', in the *Handbook of Development Economics*, Vol. 3, T.N. Srinivasan and J. Behrman, (eds.) (Amsterdam, North Holland Publishing Company).

Evenson, R.E., Herdt W., and Hossain, M. (1996): *Rice Research in Asia: Progress and Priorities* (Wallingford, UK, CAB International).

Griliches, Z. (1957): 'Hybrid Corn: An Exploration in the Economics of Technological Change', in *Technology, Education and Productivity* (New York, Basil Blackwell Inc.), pp. 27-52.

Huffman, W.E., and Evenson, R.E. (1993): 'Science for Agriculture: A Longterm Perspective', Iowa State University Press, Ames.

Johnson D., and Evenson, R.E. (1997): 'Innovation and Invention in Canada', *Economic Systems Research*, April 1997.

Judd, M.A., Boyce, J.K., and Evenson, R.E. (1986): 'Investing in Agricultural Supply: The Determinants of Agricultural Research and Extension Investment', *Economic Development and Cultural Change*, 35(1), pp. 77-113.

McKinsey, J.W. (1998): 'HYYs, Multiple-Cropping, Irrigation, Climate and the Green Revolution in India', Ph.D. dissertation, Yale University, New Haven, CT.

Mendelsohn, R., Nordhaus, W.D., and Shaw, D. (1994): 'The Impact of Global Warming on Agriculture: A Ricardian Analysis', *American Economic Review*, 84(4:88), pp. 753-771.

Pardey, P.G., and Roseboom, J. (1989): 'A Global Data Base on National Agricultural Research Systems', *ISNAR Agricultural Research Indicator Series* (Cambridge, Cambridge University Press).

Sanghi, A., Alves, D., Evenson, R., and Mendelsohn, R. (1997): 'Global Warming Impacts on Brazilian Agriculture: Estimates of the Ricardian Model', *Economia Aplicado*, 1(1).

United Nations (1992): World Population Prospects World Nutrition Database ACC-SCN.

IMPROVEMENT OF THE NUTRITIONAL VALUE OF SPECIFIC FOOD COMMODITIES

EZZEDDINE BOUTRIF and RENATA CLARKE

1. Malnutrition in Perspective

Malnutrition is a pressing problem facing humanity for which there is no single or simple solution. Eradicating hunger and malnutrition has been a fundamental objective of the world's development aid effort over the last several decades and the Food and Agriculture Organization of the United Nations (FAO) has been at the forefront of this thrust since its creation over fifty years ago. Periodically, major international meetings such as the World Food Conference in 1974, the International Conference on Nutrition (ICN) in 1992 and, most recently, the World Food Summit (WFS) in 1996, have sought to assess progress, redefine strategies and restate commitment to the struggle to adequately improve levels of nutrition globally. The latter meeting resulted in a declaration by the heads of state and other top government officials of 176 member countries which were in attendance, pledging "ongoing effort to eradicate hunger in all countries, with an immediate view to reducing the number of undernourished people by half of the present level no later than the year 2050". The number of the world's hungry was estimated then at 840 million, which is equivalent to twenty percent of the population of developing countries. Statistics presented at the Summit also indicated that over 2000 million suffer from micronutrient deficiencies – a phenomenon dubbed "the hidden hunger" during ICN.

As daunting as the current statistics on malnutrition may seem, they demonstrate considerable improvement. Thirty-five years ago about half of the population of developing countries (1 billion) were under nourished – today, that figure stands at roughly 20%. Only 10% of the world's population live in countries with very low per capita food supplies (<2200 calories), down from 56% in 1969/71. The green revolution was largely responsible for the advances, allowing food production to outstrip population growth in many countries. Progress has not been uniform across the globe, however, and in some regions food insecurity is much elevated with respect to the global average. Forty-one percent of the population in Sub-Saharan Africa, 18% in South-east Asia, 14% in Latin America and the Caribbean and 10% in North Africa and the Middle East, suffer from chronic malnutrition (Latham, 1997).

1.1. *Forms of Malnutrition*

Protein-energy malnutrition (PEM) is an important nutritional problem in many parts of the developing world and energy deficiency has been reported to be the major cause (Latham, 1997). The term covers a large number of conditions which range in degree of gravity. Failure to grow adequately is the first sign of PEM. Children suffering from PEM may demonstrate sub-normal height or weight for their age or a weight to height ratio below that which is expected. The condition is often aggravated by infections. Inadequate intake of essential amino acids in the diet through regular consumption of foods low protein content and/or poor protein quality can also lead to growth aberrations and poor development. Micronutrient malnutrition is caused by deficiency of one or more of the vitamins or minerals required for good health. The consequences of this condition depends on the particular micronutrient(s) that are deficient: the most extreme is increased mortality, but other consequences include poor cognitive development, blindness, low productivity, complications in pregnancy and increased morbidity.

Other diet-related non-communicable diseases such as obesity, cardiovascular disease, diabetes and some forms of cancer, will not be considered in the context of this presentation.

1.2. *Addressing the Problem of Malnutrition*

The experience gained in the fight against malnutrition over the last few decades illustrates the dangers of taking a narrow technical approach. The underlying cause of chronic under-nutrition is poverty. Complicating factors frequently associated with poverty include disease, unhealthy environments, social stress, discrimination, etc. The WFS Rome Declaration on World Food Security reaffirmed that "a peaceful, stable and enabling political, social and economic environment is the essential foundation which will enable States to give adequate priority to food security and poverty eradication". It went on to assert that "poverty is a major cause of food insecurity and sustainable progress in poverty eradication is critical to improve access to food". Consistent with this declaration, the WFS plan of action advocates concerted and multi-faceted action to achieve food security objectives. Sustainable solutions must take account of all salient factors. If there is inadequate consideration of the problem beforehand, limiting factors or bottlenecks may be misconstrued rendering any consequent action ineffective. Even if the problem has been correctly identified, proposed solutions must be analysed in the context of social, economic and cultural factors that influence the target population.

The ICN advocated nine common areas for action to promote and protect the nutritional welfare of the population. They are:

— Improving household food security;
— protecting consumers through improved quality and safety of the food supply;
— preventing specific micronutrient deficiencies;
— promoting breast-feeding;
— promoting appropriate diets and healthy lifestyles;
— preventing and managing infectious diseases;
— caring for the economically deprived and the nutritionally vulnerable;
— assessing, analysing and monitoring the nutritional situation;
— incorporating nutrition objectives into development policies and programmes.

Consistent with this approach, FAO has been active in promoting the development of Plans of Action for Nutrition within all member States. In this way, issues impacting upon levels of nutrition in each country can be dealt with in a cohesive and coordinated way, within the context of overall development and general improvement of living standards.

Improvement of the nutritional value of selected crops is one way of raising standards of nutrition in populations where those crops are widely consumed. In keeping with the foregoing discussion, however, it must be borne in mind that it is simply one option to be explored in formulating an overall strategy for addressing malnutrition.

Even though it represents just one element of an overall nutrition strategy, improving the nutritional value of commodities is in itself a complex question. Consideration must be given to the effect of any modification on other quality factors in relation to any given cultural context. The impact of possible improvements on the nutritional status of target populations also needs to be evaluated. Improvement could be effected through the development of new varieties with desirable nutritional characteristics which would encompass higher content of specific nutrients or reduced content of antinutritive factors. Innovations in the processing or handling of crops could also lead to increased nutritional value, by reducing losses of important nutrients, facilitating removal of antinutrient factors, permitting the addition or enhanced stability of nutrients, and so on.

2. Selected Crops of Major Nutritional Significance in Developing Countries

Ensuing discussion shall focus primarily on the scope for nutritional improvement of wheat, rice, maize and cassava. The selection of these four crops is based on their prominent role in the diets of most populations in developing countries. Table 1 shows the production of major cereals and root and tubers in selected regions in 1997.

Wheat has been the staple food of the major civilisations of Europe, West Asia and North Africa for 8,000 years and recently, throughout the developing world, *per capita* consumption of wheat has rapidly expanded. World wheat production has in fact tripled since 1950, due largely to the influence of the "green revolution". Table 2 shows the average contribution of wheat and wheat products to the diets of populations in certain developing countries.

Table 1. *Production of Selected Staple Crops in Selected Regions in 1997* (millions of MT).

Region	Item					
	Maize	Rice, paddy	Wheat	Total cereals	Cassava	Total roots/tubers
Africa	40.4	16.9	15.3	109.5	84.4	135.6
Asia	42.7	530.1	265.5	995.2	47.5	261.6
Europe	81.9	3.1	196.6	439.5	–	143.4
Latin America & Caribbean	77.3	20.1	23.4	135.0	32.2	51.1
North America	245.1	8.1	93.1	392.2	–	25.8
Oceania	0.6	1.4	19.7	31.3	0.2	3.1
Developing	249.4	530.1	265.5	1,192.5	164.3	438.8
Developed	338.6	25.7	327.4	910.1	–	181.7
World	588.0	579.7	613.6	2,102.6	164.3	620.6

Source: FAO Statistical Database.

Table 2. *Average Contribution of Wheat and Wheat Products to the Diet of Populations in Selected Developing Countries between 1992-1994.*

Country	*per capita* consumption	average daily *per capita* calorie intake from wheat		average daily *per capita* protein intake from wheat	
	(kg/yr)	(cal)	(% of total)	(g/day)	(% of total)
Albania	126.6	956	40.7	31	40.6
Algeria	203.6	1563	52.8	48	37.5
Bulgaria	154.4	1100	37.7	35	55.2
Croatia	89.4	671	28.5	20	32.7
Iran	158.2	1355	46.7	41	53.1
Iraq	98.4	816	36.0	25	47.4
Jordan	129.9	1078	39.5	33	45.3
Kazakhstan	180.1	1401	49.9	42	46.2
Lithuania	124.8	872	29.9	26	27.5
Moldova	161.6	1258	43.5	38	46.5
Mongolia	119.7	698	36.4	17	25.9
Morocco	174.5	1349	43.3	41	48.6
Tajikistan	191.8	1432	65.5	45	75.4
Tunisia	198.3	1581	49.9	48	58
Turkey	170.9	1564	44.3	51	50.3
Turkmenistan	167.9	1306	48.7	39	45.3
Uruguay	88.1	632	23.1	17	20.0
Uzbekistan	169.7	1320	50.8	39	51.8

Source: FAO Statistical Database.

Rice is the staple food of over half the world's population. Ninety-seven percent of the world's rice is grown in less developed countries, mostly in Asia. In most African and Latin American countries rice is less important than other crops: on the average, it provides less than 10% of the total calorie intake, although in Guinea, Guyana, Surinam, Liberia, Madagascar and Sierra Leone, rice plays a more prominent role in the diet.

Maize is a very important food in the Americas and much of Africa. It gives a high yield per unit area and grows in warm and fairly dry areas (although it does not tolerate as dry conditions as do sorghum or millet).

Cassava is the fourth supplier of dietary energy in the Tropics after wheat, rice and maize. The crop is tolerant to low soil fertility, drought and most pests and diseases, and has no critical date of harvest. These attributes have made cassava into a crop of major importance for the food security of farming communities living in fragile ecosystems and socially unstable environments.

Table 3. *Average Contribution of Rice and Rice Products to the Diets of Selected Developing Countries between 1992-1994.*

Country	*per capita* consumption	average daily *per capita* calorie intake		average daily *per capita* protein intake	
	(kg/yr)	(cal)	(% of total)	(g/day)	(% of total)
Bangladesh	153.9	1536	76.0	29	67.0
Cambodia	159.7	1473	81.6	30	67.4
China	92.9	936	33.9	16	23.0
Gambia	70.6	663	30.0	13	27.2
Guyana	82.9	765	31.7	15	22.2
India	75.4	747	31.2	14	24.1
Indonesia	146.5	1444	55.3	27	44.8
Korea, DPR	92	954	41.3	17	23.3
Korea, Rep.	99.4	1074	33.3	19	22.2
Laos	171.1	1514	72.9	36	65.3
Madagascar	97.9	999	48.6	22	44.7
Malaysia	90.2	790	28.4	15	23.4
Myanmar	210.5	2049	78.2	48	74.0
Nepal	86.7	801	37.7	16	29.0
Suriname	85.5	803	31.1	16	24.5
Thailand	117.8	1172	49.6	21	39.8
Vietnam	158.8	1610	70.0	33	61.9

Source: FAO Statistical Database.

Table 4. *Average Contribution of Maize and Maize Products to the Diets of Selected Developing Countries between 1992-1994.*

Country	*per capita* consumption	average daily *per capita* calorie intake		average daily *per capita* protein intake	
	(kg/yr)	(cal)	(% of total)	(g/day)	(% of total)
Angola	31.2	286	16.3	8	21.8
Bolivia	28.8	215	9.8	5	8.7
Botswana	34.8	303	13.4	8	11.1
Cameroon	32.8	285	13.2	7	13.9
Cape Verde	76.2	663	21.4	17	24.5
El Salvador	89.3	839	33.8	22	35.5
Ghana	40.3	351	14.9	9	18.1
Guatemala	108.4	1051	47.2	27	48.0

Table 4. *Continued.*

Country	*per capita* consumption	average daily *per capita* calorie intake		average daily *per capita* protein intake	
	(kg/yr)	(cal)	(% of total)	(g/day)	(% of total)
Honduras.	91.2	857	36.4	22	39.1
Kenya	92.8	807	42.1	21	42.3
Lesotho	136.7	1190	54.9	31	52.3
Malawi	139.6	1215	63.5	32	60.7
Mexico	124.4	1054	34.5	27	33.5
Mozambique	50.5	430	25.5	11	35.5
Nicaragua	60.2	563	24.8	15	27.4
Swaziland	40.2	369	13.9	10	15.7
Tanzania	73.9	661	32.2	16	32.8
Togo	62.8	516	25.1	14	28.3
Zambia	138.9	1115	57.1	29	57.1
Zimbabwe	119.7	950	47.5	25	48.8

Source: FAO Statistical Database.

Table 5. *Average Contribution of Cassava and Cassava Products to the Diets of Selected Developing Countries between 1992-1994.*

Country	*per capita* consumption	average daily *per capita* calorie intake		average daily *per capita* protein intake	
	(kg/yr)	(cal)	(% of total)	(g/day)	(% of total)
Angola	190.9	575	32.8	4	10.9
Benin	156.2	469	20.2	4	7.0
Brazil	48.6	113	4.0	1	1.5
Colombia	38.4	92.3	3.5	1	1.6
Congo, Dem. Rep	377.2	1086	53.5	6	18.8
Congo, Rep of	258.9	752	34.4	5	10.2
Cote d'Ivoire	100.3	302	12.8	2	4.1
Ghana	207.2	622	26.3	5	10.0
Indonesia	53.8	130	5.0	1	1.7
Madagascar	130.3	336	16.4	3	6.1
Mozambique	196.4	587	34.8	5	16.1
Nigeria	177.3	403	15.6	1	1.8
Paraguay	143.9	338	14.2	2	2.8
Tanzania	238.9	449	21.9	5	10.2

Source: FAO Statistical Database.

These crops are good dietary sources of carbohydrate. Although the concentration of protein in these foods is low, they are often consumed in such large quantities as to make a significant contribution to the total protein intake (tables 2-5). However, the protein quality of cereal grains is limited due to deficiencies of certain essential amino acids, mainly lysine. The protein quality of wheat, rice and maize stated as a percentage of casein, are 38.7, 79.3 and 32.1, respectively (FAO, 1992). The content of selected nutrients in the four selected staple crops is given in table 6. It is clear that mineral and vitamin contents vary significantly according to the form of any particular staple that is being considered. For example the average vitamin A content of maize flour is less than half that of the whole grain, and the mineral and vitamin content of wheat flour is substantially lower than that of the whole grain.

The question of the nutritional value of various processed forms of important staples goes beyond the fact that often some nutrients are lost in the processing. Antinutritive elements are also often eliminated during processing which tends to improve nutritive value to some extent; so although mineral content of minimally processed crops may be higher, the bio-availability of these may be considerably reduced due to the presence of other compounds.

Tables 2 to 5 show the average contribution of selected major staples to the diets of populations in certain developing countries. It must be emphasised that such national averages distort the true picture of the roles of the

Table 6. *Content of Selected Nutrients in Wheat, Rice, Maize and Cassava.*

Product	Nutrient Content in 100 g edible portion					
	Carbohydrate (g)	Protein (g)	Fat (g)	Mineral (g)	Fe (mg)	Retinol eq. µg
Wheat (whole grain)	60.97	11.73	2.00	1.80	3.31	3.33
Wheat flour	66.74	11.79	1.30	0.69	2.07	trace
Rice (unpolished)	74.06	7.22	2.20	1.20	2.60	-
Rice (polished)	77.73	6.83	0.62	0.53	0.60	-
Maize (whole grain)	64.66	8.54	3.80	1.30		184.67
Maize (flour)	66.29	8.31	2.82	1.16	2.40	50.00
Cassava	32.07	1.00	0.23	0.70	1.19	5.00

Source: Souci, Fachmann and Kraut, 1994.

selected commodities in the diets of many. Within any country there are commonly sharp distinctions in the food habits from one region to another and also between rural and urban communities. The dependence on a single staple can be substantially more pronounced for segments of the populations than the averages presented here might indicate. Despite this, the averages shown here still demonstrate heavy reliance on the selected staples. In many countries over 40% of the overall average dietary intake of calories and protein comes from one of the staples and its products. A notable exception is cassava, which due to its very low protein content makes a lower contribution to the overall protein intake of cassava-consuming populations.

3. Improvement of Nutritional Quality in Relation to Protein-energy Needs

3.1. *Energy Value of Staples*

There is general consensus that the major cause of PEM is energy deficiency (Latham, 1997). The basic cause of energy deficiency is inadequate food intake. There are also of course confounding factors of poor health and poor health care.

Carbohydrates are the single most important source of food energy in the world. They comprise from 40 to 80% of the total dietary energy intake depending primarily on cultural considerations and economic status. Foods rich in carbohydrates such as cereals, roots and tubers, generally represent the least expensive source of food energy and therefore are important in the diets of many people in developing countries.

What then are the main elements of a strategy to combat energy deficiency in populations? Poverty elimination and development of higher yielding/better growing varieties under local conditions, clearly have to be the main thrust in combating energy deficiency. Further elaboration on these areas, however, are beyond the scope of this paper. Improvement of the nutritional quality of staple crops is of secondary importance in meeting the nutritional needs of developing countries with respect to energy deficiency.

In wheat, rice, maize and cassava, starch is the major source of food energy. Although all starch has a single chemical composition (branched or unbranched polysaccharides of D-glucose) the functional and physical properties of starch can vary considerably according to its source. These differences can affect the energy value of starchy foods. Resistant starch is defined as "starch and starch degradation products not absorbed in the small intestine of healthy humans" (FAO, 1998). The energy value of starch delivered to the colon will vary according to extent of colonic fermentation. Published studies suggest that a caloric value of about 2 kcal/g is a reasonable average value for carbohydrate which reaches the colon. Consideration of the digestibility of starch and other "available" carbohydrates in the selection and promotion of varieties, could be of advantage in improving the nutritional value of high-carbohydrate staple foods.

Thickening and gelling capacity are important functional properties of starch utilised in the preparation of many traditional foods made from staple crops. Processing and preparation methods may affect the functional properties of starch and hence the nutritional value of foods prepared from them. Since many foods are prepared in such a way as to obtain a certain target consistency or viscosity (according to cultural preferences) the actual solids content of the food, and hence energy value, will vary according to the thickening and gelling behaviour of the starch under the conditions of preparation. Through processing, the functional properties of starch can be modified such that the desirable textural characteristic are obtained at a suitable level of solids and hence caloric content. This typically involves enzymatic or chemical modification.

As has been stated earlier, energy deficiency is primarily a problem of inadequate access to food. Viewed from this light, promotion of suitable preservation techniques is a useful strategy in improving levels of nutrition: in this way crops can be better maintained between harvests, improving availability of food during this period. In the case of cereals the basic criteria for achieving a long storage life is adequate reduction of moisture levels and hence water activity in the crops as well as adequate storage structures to minimise reabsorption of ambient moisture as well as to provide protection from pests and other damaging factors. Drying and storage are therefore important post-production operations. Along with promotion of increased yields, adequate measures must be taken to ensure that adequate infrastructure, facilities and knowledge exist to allow correct post-production practices. Over the last few decades there have been several examples of post-production problems that have arisen as a result of the introduction of high-yielding varieties. These include: increased susceptibility of "improved" variety to pest and disease; insufficient facilities to handle the increased volume of grain; and, inadequate drying capacity to handle the extra moisture load associated with grain that has been harvested with a higher moisture content than traditional agricultural practice. Traditionally, harvesting is carried out in the dry season, with some improved varieties, however, there can be more than one harvest per year, this means that harvesting is sometimes carried out under conditions of relatively high moisture.

Apart from the absolute loss of food material that occurs as a result of infestation during storage, there is frequently disproportionate loss in nutritional value of remaining food stores in relation to the overall weight loss. This is because the more highly nutritive parts of the plant are targeted by various pests. Weevils feed especially on the endosperm which is rich in carbohydrate, other parasites target the protein and vitamin-rich germ. This selective attack reduces the nutritional value of residual food supplies per unit weight with respect to the targeted nutrients (Grolleaud, 1997). Appropriate consideration must be given to these factors if nutritional and economic benefits promised by new production technologies are to be fully realised.

The need for suitable processing technologies for roots and tubers is even greater given the high perishability of these crops. In the case of cassava for instance, onset of spoilage occurs within 48-72 hours after harvesting.

3.2. *Protein Value of Staples*

The nutritional value of proteins is related to their ability to meet human amino acid and nitrogen requirements for growth and maintenance. The protein quality of cereals is limited by deficiencies of certain essential amino acids, mainly lysine. Table 7 presents a comparison of the amino acid composition of the four major staples and their amino acid scores.

Biotechnology

Biotechnology has been used to address the problem of poor protein quality in cereals, perhaps most successfully in maize. The known genetic variability for lysine in common wheat protein is quite low and the search for high lysine mutants in wheat has been unsuccessful (Heger *et al.*, 1990).

Table 7. *Amino Acid Content of Whole Grain Cereals and Cassava.*

Amino acid (g/16g N)	Wheat	Brown rice	Maize	Cassava
Lysine	2.3	3.8	2.5	6.3
Threonine	2.8	3.6	3.2	3.4
Methionine + cystine	3.6	3.9	3.9	2.6
Tryptophan	1.0	1.1	0.6	1.0
Amino acid score	40	66	43	91

Source: FAO, 1993.

A decrease in lysine concentration in wheat protein is associated with an overall increase in protein content. Only slight improvement in lysine content of wheat is therefore realised in high protein varieties. So far nutritional differences among commonly grown wheat varieties are small.

The feasibility of using biotechnology to achieve improved protein quality in maize was demonstrated more than 30 years ago when Dr. E.T. Metz and co-workers reported on the effect of the opaque-2 gene on improving the amino acid content and balance in maize proteins. Since that time another mutant gene, floury-2, has also been shown to be important in improving maize protein quality.

Like most cereals, maize seeds contain three main types of proteins, namely storage proteins, enzymes involved in metabolism and structural proteins. The prolamine storage proteins account for approximately half of the total protein content, and are devoid of lysine and tryptophan. Both opaque-2 and floury-2 genes in maize suppress the synthesis of prolamines, resulting in a significant increase in lysine and tryptophan (Zarkadas, 1997).

Acceptance of opaque-2 genotypes was limited due to their soft, chalky endosperm, lower yields and increased susceptibility to pests and disease. Through backcrossing and several cycles of recurrent selection, however, maize breeders have been able to combine the high lysine potential of the opaque-2 gene with endosperm modifiers and have developed new cultivars similar in yield and other agronomic characteristics to normal maize. These new maize inbreds are collectively known as quality protein maize (QPM).

Several studies have demonstrated through feeding trials the improved nutritional value of QPM (Bressani, 1991). Based on nitrogen balance studies carried out by the Institute of Nutrition of Central America and Panama (INCAP), it was calculated that 24g of normal maize per kg bodyweight was required for nitrogen equilibrium as compared with 8g of opaque-2 maize. On the basis of a 15 kg – bodyweight child, this means that nitrogen equilibrium could be obtained with an intake of 360g of normal maize whereas only 120g of opaque-2 maize would be required. The protein quality of common maize and opaque-2 maize are 32.1 and 96.8, respectively, expressed as a percentage of casein.

Apart from the improved lysine and tryptophan content of the opaque-2 maize, another advantage is the reduced leucine: isoleucine ratio. The large amount of leucine hinders absorption of other essential amino acids, particularly isoleucine. Despite the improved protein quality of the high lysine maize varieties, their adoption rate has been so far quite low. During a recent project in Ghana, however, there were signs of a high level of acceptance of a QPM variety that had been developed (van Dorp, 1997). The QPM variety had good disease and drought resistance characteristics, met

Table 8. *Essential Amino Acid Content and Chemical Score of Normal and High Lysine Maize.*

Amino Acid	Maize		FAO/WHO pattern	Chemical Score	
	Normal	High Lysine		Normal	High Lysine
Lysine	177	256	340	0.52	0.75
Isoleucine	206	193	250	0.82	0.77
Leucine	827	507	440	1.87	1.15
Total sulphur aa	188	188	220	0.85	0.85
Total aromatic aa	505	502	380	1.32	1.32
Threonine	213	199	250	0.85	0.79
Tryptophan	35	78	60	0.58	1.30
Valine	292	298	310	0.94	0.96

Souce: Bressani, 1991.

consumer preferences, allowed greater flexibility to farmers in the planting date as it had a slightly shorter maturity time than local varieties and, was higher yielding than the best available local variety. The QPM variety was handled through normal maize marketing channels and was available to consumers at the same price as other varieties. The new QPM variety has accounted for over half of commercial seed sales since 1993. This example illustrates the importance of taking socio-economic and cultural factors adequately into consideration in planning and implementing any nutrition intervention.

High protein rice varieties have also been developed in order to improve the nutritional value of this staple. The protein content of the improved varieties ranges roughly between 10% to 12%, and the improvement in total protein content does not adversely affect protein quality as is usually the case with wheat and maize. Improved protein varieties of sorghum and barley have also been developed.

Antinutritional Factors

Nutritional quality of a food does not only depend on its nutrient composition, but also on the availability of these nutrients for absorption and utilisation by the body. Antinutritional compounds occur in cereals although their importance is relatively low with respect to their significance in leguminosae, for example.

Digestibility of whole wheat and white wheat flour are given as 90% and 96%, respectively (FAO, 1990). Although the protein content of brown rice is higher than that of polished rice, the protein value is about the same due to the reduced digestibility in the former (FAO, 1993). Gupta *et al.* (1989) also reported increased values for true protein digestibility in maize process flour as compared with the whole grain. The differences in digestibility described here are due to the loss of various compounds during milling of the grains which inhibit protein digestion. Anitnutritional compounds in cereals include trypsin and other proteinase inhibitors, haemaglutinnins (lectins), tannins, saponins and phytins. Traditional plant breeding and varietal selection can be used to develop or promote varieties or cultivars with lower contents of antinutritional factors. Processing can also reduce levels/activity of these undesirable components. Proteinase and amylase inhibitors as well as haemaglutinnins are proteinaceous and exposure to moist heat will readily reduce their activity. Roasting and malting were shown to substantially reduce levels of phytates, saponins and polyphenols in wheat (Gahlawat and Sehgal, 1993). It is important to note, however, that changes occurring during processing and preparation of foods are complex and interactions among food components may lead to decreased bio-availability of nutrients. It is important, therefore to be aware of the possibilities and promote processing and preparation practices that optimise nutritional value consistent with cultural food preferences of the population.

The utilisation of cassava for food is influenced by the potential toxicity of this crop. Cassava contains the cyanogenic glucosides, linamarin and lotaustralin. When cellular disruption occurs these compounds react with linamarase, an enzyme which is also naturally present in the cassava, to produce acetone cyanohydrin and glucose. At a pH level above 5, or in the presence of another enzyme naturally occurring in the plant, the acetone cyanohydrin breaks down to liberate hydrogen cyanide, a potent toxin. Given the low boiling point of this toxin, it dissipates quickly into the atmosphere: in this way the toxicity of the final food, if carefully processed can be greatly reduced. Persistent high consumption of cassava has been associated with various diseases and nutritional disorders: tropical ataxic neuropathy, goiter and cretinism, spastic paraparesis, or konzo (Bokanga, 1998). The cassava root has a very low protein content, but the cassava leaves have good protein value, utilisation of the leaves, therefore is an important strategy in optimising the nutritional benefit of the crop. The cyanogenic potential of the leaves, however, is much higher than in the root.

Through cassava breeding programmes, crops with reduced cyanogenic potential in the root and in the leaves should be promoted if they also present desirable agronomic characteristics.

Amino Acid Fortification

Amino acid fortification is another way to improve the nutritional value of selected foods. The appropriateness of this route depends on the consideration of several factors. Since the addition of the amino acids must take place at a central processing facility, this means that the target group must procure their food through the designated market channels, if they are to benefit from this form of nutritional improvement. This pre-condition excludes vulnerable populations that consume foods which they have produced and processed themselves. It is also critical to ascertain that such a specific and narrow intervention is indeed nutritionally indicated. The amino acid deficiency must be clinically demonstrated in the population beforehand and subsequent monitoring must indicate that the nutritional objectives are being achieved. An important consideration in planning amino acid fortification is the manner in which the food is handled and processed up to consumption. Lysine loss during storage, processing and food preparation is a common phenomenon and could jeopardize achievement of the intervention. A reliable estimate of anticipated losses is necessary in determining the level of fortification required.

Maillard browning is one the many reactions known to occur in many food systems. It generally involves reaction between an amino-bearing compound, usually a protein, a reducing sugar and some water and results in the formation of brown polymeric compounds. Lysine, with its free epsilon amino group is particularly susceptible to interaction with reducing sugars in the Maillard reaction. When an amino acid or part of a protein chain takes part in the Maillard reaction it is lost from a nutritional stand point. The nutritional significance of this is that in processed cereal foods there can be a further reduction in lysine content, which is already the first limiting essential amino acid in cereals. This can reduce substantially the nutritional value of processed staples.

It must be emphasised that amino acid imbalance in one commodity can be counteracted by consumption of other foods with complimentary amino acid patterns. Nutrition education programmes are important tools in influencing dietary habits and achieving sustainable nutritional improvement in the overall diet.

4. Improving Nutritional Quality in Relation to Micronutrient Requirements

Improving micronutrient content of staple crops would certainly be of value in reducing the incidence of micronutrient deficiency in populations that have poor dietary diversity. In countries where there is heavy reliance on rice as food, there is common occurrence of vitamin A deficiency, nutritional anaemia, thiamine and riboflavin deficiencies due to poor supplies of these nutrients in the diet. Niacin deficiency is commonly associated with maize-eating populations due to the fact that niacin in this commodity is present in bound form that is not readily bioavailable. Processing may render this bound vitamin available for absorption by the body.

4.1. *Processing*

The vitamin and mineral content of whole wheat compared with white wheat flour, brown rice compared with polished white rice and whole grain maize compared with maize meal, demonstrate the influence of processing on nutritional value in relation to micronutrient requirements (table 9).

Table 9. *Micronutrient Content of Selected Staples.*

Component	Whole wheat	White wheat flour	Brown rice	Polished rice	Whole maize	Maize flour	Cassava
Retinol eq. (µg/100g)	3.33	trace	0	0	185	50	5.0
Vitamin E activity (mg/100g)	1.35	0.62	0.74	0.18	2.01	2.01	na
Thiamine (µg/100g)	459	260	410	60	360	440	60
Riboflavin (µg/100g)	107	60	91	32	200	130	30
Niacin (mg/100g)	5.10	0.89	5.2	1.3	1.5	1.93	0.6
Pantothenic acid (mg/100g)	1.18	0.63	1.7	0.63	0.65	0.55	na
Pyridoxin (µg/100g)	269	280	275	156	400	60	na
Biotin (µg/100g)	60	2.9	12	3	6	6.6	na
Folic acid (µg/100g)	87	22	16	29	26	10.1	na
Vitamin C (µg/100g)	0	0	0	0	0	0	30
Iron (mg/100g)	3.31	2.07	2.60	0.6	4.8	2.4	1.19
Zinc (mg/100g)	2.69	1.63	1.52	0.5	2.5	na	0.55

Taken from Souci, Fachman and Kraut, 1994.

During the milling process the outer layers of cereal grains are removed resulting in loss of associated nutrients. To improve vitamin nutritional value of diets based heavily on cereals, nutrition education programmes can be used to educate the population on the improved vitamin content of the less processed grains. With respect to minerals, there is a relatively high content of compounds which inhibit bioavailability, so even the minimally processed grain is a poor source of the multivalent minerals. The antinutritional compounds that inhibit the bioavailability of multivalent minerals include phytates, oxalates and other compounds that preferentially bind with the mineral ions rendering them unavailable for absorption into the body.

Parboiling improves the micronutrient content of milled rice. This involves the soaking of rough rice and the application of heat followed by drying and milling. It has been demonstrated that parboiling can lead to the retention of 50%-90% of thiamine. In the case of maize, lime treatment causes bound niacin to be converted to a bioavailable form thus improving the micronutrient value of the staple.

4.2. *Biotechnology*

Most research into the biotechnological improvement of the micronutrient value of foods has been directed at vitamin A, zinc and iron in various crops. The possibility of improving iodine content of cassava is also receiving attention. Cassava contains cyanogenic compounds which can decompose into cyanide on consumption. This is detoxified within the body by conversion to thiocyanate which has a known goitrogenic effect: it interferes with the ability of the body to use a limited supply of dietary iodine. If iodine intake is adequate, a high thiocyanate load does not have a goitrogenic effect.

Biotechnology represents a new and exciting tool for the improvement of micronutrient quality of crops. However, considerable preliminary work is required before the improvement of the micronutrient value of staple crops through biotechnolgy can become a reality. Researchers must first of all determine the range of genetic variability available for exploitation in breeding programmes; the bioavailability of the micronutrients in new varieties; the genetics and biochemistry/physiology of selected traits; and, screening protocols to be used in breeding programmes (Welch *et al.*, 1997). A large amount of human and financial resources will be required to implement such a programme of work.

The genetics of carotene biosynthesis have been characterised in some crops such as tomato, maize and carrot. Major genes controlling the carotene content of several additional fruit and roots have been identified

(Simon, 1992). Genetic studies so far suggest that there is considerable potential for increasing the carotene content of maize, sweet potato, tomato, carrots as well as other fruit and root crops. These genetic changes would provide several health benefits without otherwise modifying the diet. The yellow or orange pigment resulting from the genetic improvement of carotene content may require that consumer education be carried out to ensure acceptance of high carotene varieties.

Yellow endosperm maize contains from 20 to 40 μg per gram of total carotenoids, but only 10 to 20% of these show pro-vitamin A activity. Current understanding of the genetic control of the type and amount of carotenoids in the maize kernel makes it possible to breed for higher vitamin A activity in this crop. This would make an important contribution to increasing the dietary supplies of this vitamin, in a sustainable way, to populations in many developing countries (Simon, 1992).

Progress is being made in research to determine the potential for increasing pro-vitamin A carotenoid synthesis in rice endosperm through genetic engineering. Investigation of the biochemical properties of rice endosperm showed the presence of geranyl geranyl diphosphate, a precursor necessary for C40 carotenoid biosynthesis. Phytoene synthase catalyses the condensation of two molecules of geranyl geranyl diphosphate and is the first step in the biosynthesis of carotenoids. DNA coding for the synthesis of this enzyme from daffodil was introduced into rice. The daffodil enzyme has been shown to be active in the transgenic rice (Burkhardt *et al.*, 1997). This is an important step towards the goal of developing vitamin A rich rice varieties. The quantity of carotenoids required to achieve nutritional objectives is sufficient to cause yellow colouration of rice grains. Consumer education will be required to ensure acceptance of such an innovation.

Principle plant foods are poor sources of dietary iron because they contain low levels of dietary iron and they also contain compounds that inhibit iron absorption. Supplying more iron to seed and grain crops during growth does not substantially increase iron content in plant foods because iron absorption, translocation, distribution and deposition in plant organs are controlled by homeostatic mechanisms. Once the genetics of this control mechanism are characterised, it may be possible to develop new varieties which accumulate greater quantities of available iron in their edible parts (Welch and Kochan, 1992). Similar research is being carried out on zinc (Welch *et al.*, 1997).

Increase of available iron by targeting seed ferritin control through biotechnology and breeding is being attempted. Ferritin is a natural iron storage compound in both plants and animals and is a normal seed component. Prospects for success with this approach are encouraging as ferritin seems to be under accessible genetic control. Recent studies have shown good bioavailability of this iron source.

4.3. *Micronutrient Fortification*

Micronutrient fortification is another tool for achieving improvement in the nutritional value of commodities. Food fortification is defined as the addition of one or more essential nutrients to food, whether or not it is normally contained in the food, for the purpose of preventing or correcting a demonstrated deficiency in the target population. To be effective, the food being fortified must meet certain conditions: it must be consumed in roughly constant quantities throughout the year by most of the target population; the food must pass through a centralised point to facilitate a rigidly controlled fortification process; and, the addition of nutrients at the required levels must not affect the organoleptic qualities of the food (Clarke, 1996).

It is important to emphasise that micronutrient fortification is not universally applicable. In some cases the high degree of decentralisation of food processing activities makes it impossible to regulate or even establish a viable fortification programme. In cases where subsistence farming is practised, fortification is not likely to be a practicable approach to improving the micronutrient quality of foods. It is imperative therefore, before embarking on food fortification activities, to carefully analyse the context in which it is being considered.

Fortification of flours produced from the major staples does not present many technological difficulties. The appropriate fortificant compounds simply have to be dry mixed with the flour. Care must be exercised in the selection of the fortificant compound and in the mixing process so as to ensure that the fortificant is uniformly distributed and that segregation on storage is minimised. In many countries addition of thiamine, riboflavin, niacin, iron and calcium to wheat flour is a common practice aimed at restoring nutrients lost during the milling process. There have been several reports of the technological feasibility of adding other nutrients as well to wheat flour as well as corn meal. These nutrients have included vitamin A, pyridoxine, folic acid, tocopherol acetate, magnesium and zinc. Fortification of cassava meal or flour could be carried out according to the same principles.

Fortification of rice grains presents various problems, but several procedures have been developed for the fortification of this commodity. In powder-type enrichment processes, a powdered pre-blended mixture of vitamins and minerals is added to the rice. For white parboiled rice, the normal practice is to add the nutrient mixture soon after milling as the heat and moisture at the grain surface facilitates adherence of the powder. A major disadvantage of this approach is that 20% to 100% of nutrients are lost on washing, which is a common step in the preparation of rice in many developing countries.

'Grain type' fortification involves the application of the nutrient mixture by various means followed by the application of a water insoluble coating. These coatings minimise vitamin loss on rinsing but dissolve at the elevated temperatures experienced during cooking. Good results have been obtained with various procedures of this type, although colour deterioration can be caused by riboflavin and vitamin A.

Fortification of rice through the inclusion of simulated grains has been attempted on a limited scale with promising results. The simulated rice grains were produced by extrusion of rice flour containing vitamin A stabilised by tocopherol acetate and lipids with a low degree of unsaturation.

5. GENERAL CONSIDERATION IN IMPROVING THE NUTRITIONAL QUALITY OF SELECTED COMMODITIES

Agricultural development requires concerted input from a range of disciplines. Economists, social scientists, natural scientists and a range of technicians must be involved in analysing the agricultural sector, identifying development objectives, prioritising them and then identifying constraints in the system that have to be addressed in formulating a viable and effective strategy for agricultural development. Adequate investment in this upstream planning process would pay off in terms of less wastage of manpower and money on poorly designed projects, the elaboration of fundable projects and effective use of resources in their implementation.

In trying to project the needs of major food commodities for the first half of the next century, the role of the improvement of nutritional quality of commodities has to be understood in relation to an overall plan for agricultural development. Such a plan within each country should be the outcome of the process outlined in the preceding paragraph.

Biotechnology has certainly emerged, over the last two decades, as a powerful tool to be used in many areas of agricultural development, including improvement of the nutritional quality of a range of commodities. Biotechnological research is more expensive than conventional research, however, and countries need to carefully consider the pros and cons of seeking biotechnological solutions. In cases where biotechnology does present clear advantages, there are several issues that must be recognised and solved before the potential of biotechnology can be harnessed in the pursuit of agricultural development around the world (FAO, 1999).

Several years of research and substantial funding would be required to realise the objectives of any biotechnology programme. In deciding to adopt biotechnology a country must therefore commit substantial ongoing financial support. Such research requires skilled staff, well equipped laboratories and a high level of institutional support. It must be stressed that a substantial body of conventional research is a fundamental prerequisite for embarking on biotechnology programmes. International networks may be necessary to provide the required critical mass of expertise, knowledge and facilities. A minimal technology base is required even to adapt technology established elsewhere, to local conditions. Adequate outreach and extension staff is also required to successfully transfer the technology to the end user.

All World Trade Organization (WTO) members are bound by the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS). The lack of patent protection in a country can limit access to results of biotechnology originating elsewhere. Countries need to evaluate their positions and, as appropriate, introduce legislation as foreseen in the WTO Agreement.

Countries need to ensure safety of food arising from biotechnology. The Codex Alimentarius Commission is considering development of a general standard which would apply basic food safety and food control disciplines to foods derived through biotechnology. Foremost amongst considerations are potential allergenicity, possible gene transfer from GMOs, pathogenicity deriving from the organisms used, nutritional considerations and labeling.

Governments must be aware of the risk of reducing genetic diversity by displacing landraces and their inherent diversity and take any necessary action to safeguard against this.

While noting that considerable preparation needs to be made before biotechnology can be effectively exploited as a tool for improving the nutritional quality of foods, it must be recognised that in many developing countries conventional scientific research for agricultural development on the whole, is poorly supported. There is considerable scope through conventional science, for improving the nutritional quality of selected commodities. Applied research involving studies on compositional differences in crops due to variety or agronomic practices, traditional plant breeding, investigation of effects of processing techniques on nutritional factors, development of techniques which enhance nutritional quality could realistically be undertaken by most developing countries and would make an important contribution to the knowledge base to support interventions aimed at improving nutritional quality of foods. This will only be realised if there is substantial investment in science in developing countries and a reconsideration of its role in agricultural development.

6. CONCLUSIONS

There is considerable scope for improving nutritional quality of foods and the ever-widening possibilities offered by various biotechnologies point to even greater scope for sustainable solutions to malnutrition through improved nutritional quality, in the future.

It is important to have neither a disjointed nor a narrow vision for raising levels of nutrition around the world over the next decades. There are several valid approaches covering: development and introduction of higher yielding varieties; development and introduction of varieties better adapted to certain agro-ecological zones; improved marketing systems; nutrition education; dietary diversification; improved nutritional quality of crops; and, income generation. In any situation, the optimal solution is likely to involve a combination of approaches modified and adapted to the particular context in which it is to be applied.

REFERENCES

Bokanga, M. (1998): *Post-Production Compendium - Cassava* (in press, FAO, Rome).

Bressani, R. (1991): 'Protein Quality of High-Lysine Maize for Humans', *Cereal Foods World*, 36, 9, pp. 806-811.

Burkhardt, P.K., Beyer, P., Munn, J., Kloti, A., Armstrong, G.A., Schledz, M., Lintig, J., Potrykus, I., and Von Lintig, J. (1997): 'Transgenic Rice Endosperm Expressing Daffodil Phytoene Synthase Accumulates Phytoene, a Key Intermediate of Provitamin A Biosynthesis', *Plant Journal*, 11, 5, pp. 1071-1078.

Clarke, R. (1996): 'Food Fortification: Technology and Quality Assurance', in *Food and Nutrition Paper 60, Report of FAO Technical Consultation, Rome, 21-23 Nov. 1995* (FAO, Rome).

FAO (1992): *Maize in Human Nutrition. FAO Food and Nutrition Series, No. 25* (FAO, Rome).

FAO (1993): *Rice in Human Nutrition. FAO Food and Nutrition Series, No. 26* (FAO, Rome).

FAO (1998): *Carbohydrates in Human Nutition. Food and Nutrition Paper 66* (FAO, Rome).

FAO (1999): *Biotechnology, Committee on Agriculture, 15th Session, Rome, 25-29 January 1999* (FAO, Rome).

Gahlawat, P., and Sehgal, S. (1993): 'Antinutritional Content of Developed Weaning Foods as Affected by Domestic Processing', *Food Chemistry*, 47, 4, pp. 333-336.

Grolleaud, M. (1997): *Post-Harvest Losses* (in press, FAO, Rome).

Gupta, H.O., Prakah, O., and Jodinger, S. (1991): 'Influence of Endosperm Texture on Milling, Chemical Composition and Nutritive Quality in Maize', *Plant Food for Human Nutrition*, 39, 3, pp. 235-243.

Heger, J., Salek, M., and Eggum, B.O. (1991): 'Nutitional Value of some Czechoslovak Varieties of Wheat, Triticale and Rye', *Animal Feed Science and Technology*, 29, 11-2, pp. 89-100.

Juliano. B.O. (1998): 'Varietal Impact on Rice Quality', *Cereals Food World*, 43, 4, p. 207.

Khan, M.A., Rana, I.A., and Ullah, I. (1989): 'Nutritional Evaluation of some Commercial Wheat Varieties Grown in Pakistan', *Plant Foods for Human Nutrition*, 37, 3, pp. 253-260.

Latham, M.C. (1997): *Human Nutrition in the Developing World* (FAO, Rome).

Naikare, S.M., and Ingle, N.J. (1988): 'Studies on Cooking and Nutritional Qualities of Different Varieties of Rice', *Journal of Maharashtra Agricultural Universities*, 13, 1, pp. 96-97.

Roozendaal, G. (1996): 'A Second Green Revolution?', *Biotechnology and Development Monitor*, 29, pp. 12-15.

Simon, P.W. (1992): 'Genetic Improvement of Vegetable Carotene Content', in *Biotechnology and nutition*, editors, Donald D. Bills and Shaun-dew Kung (Butterworth-Heinemann, Boston), pp. 291-300.

Sotelo, A., Hernandez, M., Montalvo I., and Sousa, V. (1994): 'Amino Acid Content and Protein Biological Evaluation of 12 Mexican Varieties of Rice', *Cereal Chemistry*, 71, 6, pp. 605-609.

Souci, S.W., Fachmann, W., and Kraut, H. (1994): *Food Composition and Nutrition Tables, 5th edition* (Medpharm Scientific Publishers, Stuttgart).

Van Dorp, M. (1997): *FAO Case Study - Nutrition Considerations in Agricultural Research* (Presented at FAO workshop on incorporating nutrition in agricultural research, Accra, 4-5 Nov. 1997).

Welch, R.M., West, C.E., and van der Haar, F. (1997): 'Agronomic Problems Related to Provitamin A in Carotenoid-rich Plants', *European Journal of Clinical Nutrition*, 51, supplement 4, S34-S38.

Welch, R.M., and Kochan, L.V. (1992): 'Regulation of Iron Accumulation in Food Crops', in *Biotechnology and Nutrition*, editors, Donald D. Bills and Shaun-dew Kung, (Butterworth-Heinemann, Boston), pp. 325-344.

Zarkadas, C.G. (1997): 'Asessment of the Protein Quality of Native White Floury Maize, Designated IAPO-13, by Amino Acid Analysis', *Journal of Agricultural an Food Chemistry*, 45, 4, pp. 1062-1069.

IV.

PHYSICAL AND BIOLOGICAL FACTORS NEEDED IN FOOD PRODUCTION

SOME POTENTIAL IMPACTS OF CLIMATE CHANGE ON FUTURE FOOD PRODUCTION IN DEVELOPING COUNTRIES

STANLEY J. ULIJASZEK

INTRODUCTION

Climate is the statistical construct which is used to describe average weather and its variability across periods of time (Trenberth *et al.*, 1996), while climate change has been defined as any change in climate over time whether due to natural variability or as a result of human activity (Houghton *et al.*, 1996). The internal interactive components of the climate system include the atmosphere, oceans, the land and its natural features including vegetation and ecosystems, snow cover, sea and land ice, and hydrology (Trenberth *et al.*, 1996). These factors, in addition to external ones including the distribution of land and ocean masses, composition of the atmosphere and oceans, the energy output from the Sun, the changing orbit of the Earth around the Sun, and Sun-Earth geometry, determine climatic variability due to natural causes.

While natural climatic variability is well studied (e.g. Winstanley, 1973; Nieuwolt, 1977; Henderson-Sellers, 1992; Cubasch *et al.*, 1995; Dickinson *et al.*, 1996; Nicholls *et al.*, 1996), the study of climate change specifically as a consequence of human activity is of more recent origin (Angell, 1988; Christy and McNider, 1994; Nicholls *et al.*, 1996). Human-induced changes in climate can only be detected by the separation of the anthropogenic effect from a background of natural climate variability (Houghton *et al.*, 1996).

The increased emission of radiatively active gases, especially carbon dioxide and sulphate aerosols (Schimel *et al.*, 1996) has been linked with observed increases in global temperature (Houghton *et al.*, 1990; Jones, 1988, 1994) due to their potential for radiative forcing by changing either the reflection or absorption of solar radiation, or the emission and absorption of terrestrial radiation (Houghton *et al.*, 1996). Although changing patterns of global rainfall may not be related directly to all types of anthropogenic forcing, there is evidence to suggest that with increasing global temperature rainfall events will be more intense (Houghton *et al.*, 1992) leading to more intense rainfall seasonality, where such seasonality is already present (Arnell *et al.*, 1996).

While the predictive modelling of climate change is fraught with problems, validations of surface air temperature models against real temperature trends derived from satellite-based observations show no serious inconsistencies (Hansen *et al.*, 1995). However, satellite based observations have been collected for little over 20 years, and this short time-frame limits their utility for the detection of potential anthropogenic temperature change, as well as for their validation of climate-change models (Santer *et al.*, 1996). The initial evidence for anthropogenic climate change is clear at the global level (Santer *et al.*, 1996), but is likely to become discernible at regional levels only in future years (Karl *et al.*, 1991). Increasing global temperature has been clearly predicted, although the range of temperature values projected to future years is extremely broad, and reflects the various data, mathematical functions, and assumptions used in different models (Houghton *et al.*, 1996). Predictions of sea-level rise, changing rainfall pattern, and food production, all models secondary to predicted global temperature change, employ further sets of data and assumptions, and therefore the accuracy of prediction must be much lower than that of global surface temperature change. Furthermore, biases in simulated regional changes in climate are too large to allow a high degree of confidence in them (Houghton *et al.*, 1996; Watson *et al.*, 1998). Thus, the interpretation of outcomes from all predictive modelling of climate change and its impact on food production must be extremely cautious; future climate scenarios are described as projections, not predictions, acknowledging the low accuracy of current modelling procedures (Houghton *et al.*, 1996; Watson *et al.*, 1998).

The impact of climate change on human ecosystems is likely to be both: 1) direct, related in large part to changes in temperature and rainfall patterns; and 2) indirect, associated with changes in the abundance of plant species and genotypes within species, as well as global geographic distributions of species (Melillo *et al.*, 1996). Direct effects will influence the type and pattern of food crop use possible for predominantly agriculturally-based populations, while indirect effects will influence patterns of subsistence for more traditionally-oriented societies practicing one or more of the following: hunting, gathering, simple horticulture, slash and burn agriculture, pastoralism, and agro-pastoralism. Both direct and indirect effects will change the types and patterns of pest and plant disease infections, and will thus influence influence food production indirectly.

Food production in the less developed world in the first part of the twenty-first century will depend on a number of interrelated factors (figure 1). These include the following: 1) changing patterns of temperature and rainfall; 2) the impact of these patterns on all tropical ecosystems; 3) changing human impact, both positive and negative, on these ecosystems; 4) changing population size and structure; 5) changing sea levels on land inundation and its impact on agricultural productivity; 6) changing patterns of rainfall and temperature uncertainty and the human responses to them; 7) climatic patterns influenced by El Niño effects making regular seasonal patterns more difficult to discern and predict at local level; and 8) socio-economic and technological factors which mediate the human subsistence production response to climate change.

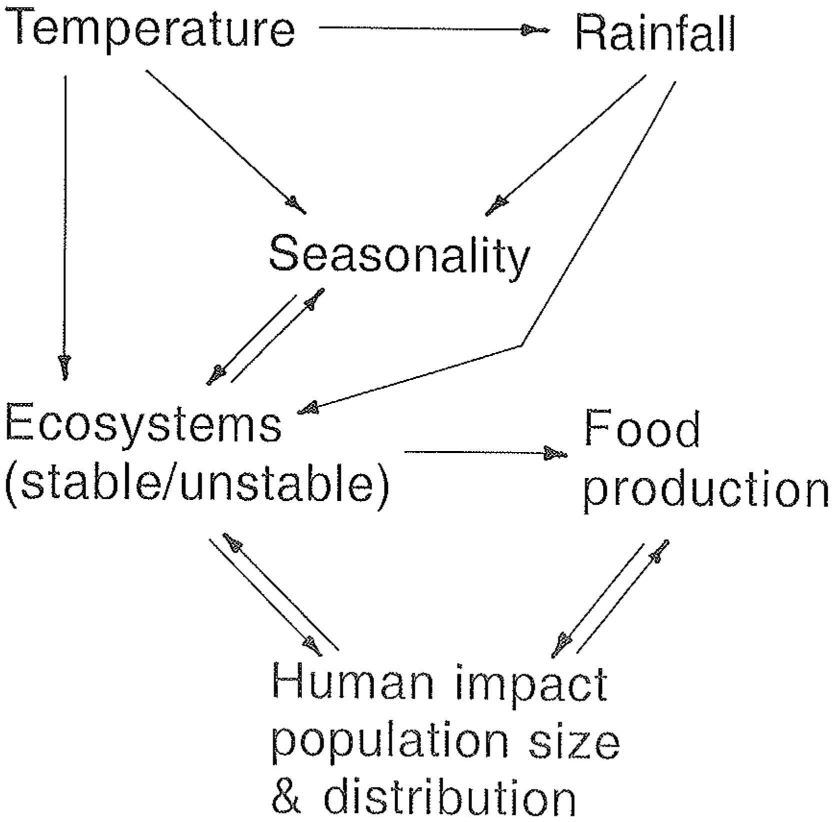

Fig. 1. Relationships between climatic variables, human ecosystems and food production.

In this article, projected patterns of temperature, rainfall and sea level changes are described for the period to 2050, and the potential impacts of such change on human populations and their food production systems examined. The validity of these descriptions depends to a very large extent on the accuracy of assumptions made when building and running climate change models. Given that the extent of future change in emissions of gases which force radiative change is unknown (because of their dependence upon unpredictable global patterns of political, economic and human behavioural change), projections of future climate must be tentative at best, regardless of the accuracy of modelling.

PREDICTED CLIMATE CHANGE

Predictions of climate change use general circulation models (GCM) of the coupled climate system, which is composed of the oceans, cryosphere, land surface, and atmosphere (Gates *et al.*, 1993). Such coupled models include the three dimensional representation and interaction of these components on a global, time-dependent basis (Gates *et al.*, 1996). They can be used to predict a range of outcome measures including global and regional temperature, rainfall patterns and sea level change, using integrations in which physical data including background climatic variation, atmospheric composition and surface vegetation are specified, across periods into the future (Gates *et al.*, 1996). Simulations require integrations across extensive periods into the future (Stouffer *et al.*, 1994) and computational cost usually restricts model complexity and degree of resolution possible (Gates *et al.*, 1996). Such GCMs rely on a good understanding of underlying climatic processes (Kattenberg *et al.*, 1996). Thus far, the influence of cloud formation and cover, the hydrological cycle and variation in land-surface vegetation on climate remain the largest areas of uncertainty in predictive modelling, and are the largest sources of variation across models developed (Gates *et al.*, 1996; Neilson, 1998). The accurate projection of climate change is as much contingent upon improved understanding of climatic systems, and the degree of resolution possible with given computing possibilities, as upon correct prediction of changes in the degree of solar radiation and known climatic variables impacting on the earth in coming decades (Kattenberg *et al.*, 1996).

Simulations can be carried out with no external forcing, in which current climate trends are projected into the future. Against this background, the effects of changing atmospheric greenhouse gas concentrations and aerosol content on temperature, rainfall, or soil moisture can be projected by incorporating the known effects of these substances on radiation in a mathematical model. A wide range of models have been developed and summaries of assumptions made by a number of them are given in Gates *et al.* (1996), Kattenberg *et al.* (1996), Giorgi *et al.* (1998) and Neilson (1998). The extreme range of possible change in global mean temperature by the year 2050 is between 0.3 and 2.0 degrees celcius above a 1990 baseline value (Kattenberg, 1996), incorporating a range of climate sensitivity values of between 1.5 and 4.5 degrees celcius increase above baseline to a doubling in atmospheric carbon dioxide concentration (Houghton *et al.*, 1996). However, global mean surface temperature change projections based on a 'best estimate' value for climate sensitivity of 2.5 degrees celcius to a doubling of atmospheric carbon dioxide concentration give far less variation (figure 2). Against a 1990 baseline value, global mean temperature is projected to rise by between 0.8 and 1.0 degrees celcius by the year 2050.

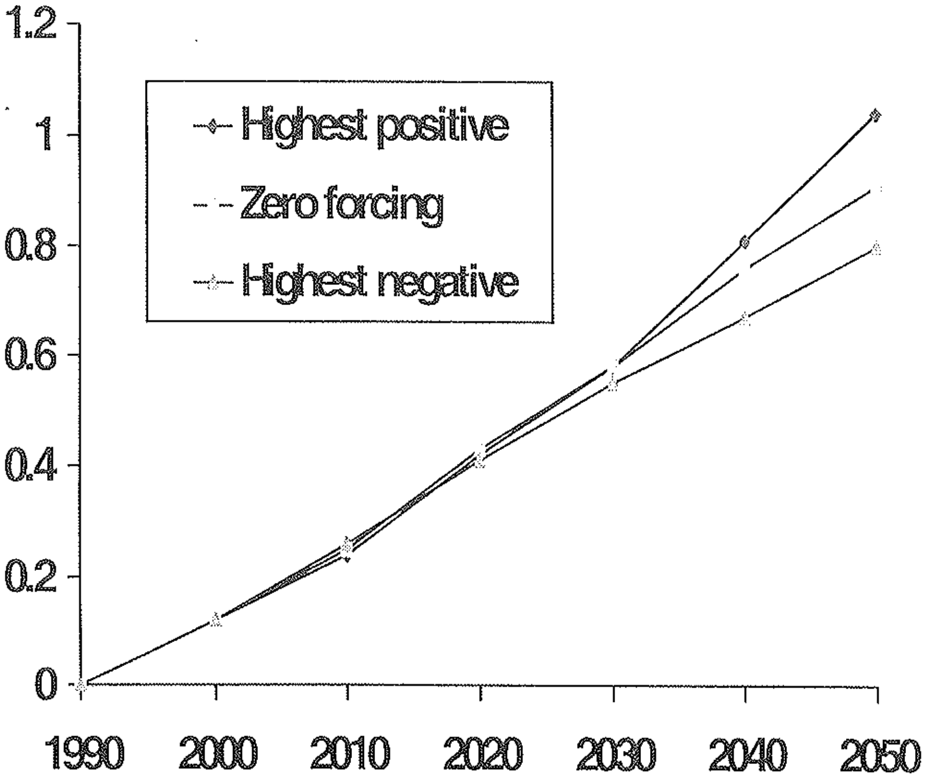

Fig. 2. Projected global mean surface temperature changes (degrees celsius), 1990-2050, the 1990 value set at zero. A climate sensitivity of 2.5 degrees celsius increase in global temperature is assumed for every doubling of atmospheric carbon dioxide concentration. Adapted from Houghton *et al.*, 1996.

Projected mean sea level rise due to global warming has been estimated by modelling using similar conditions for changes in emissions of greenhouse gases and aerosol precursors. The combined contributions of the Greenland and Antarctic ice sheets to rising sea-level are projected to be relatively small, although a mean increase in sea level of about 20cm is predicted by the year 2050, due mostly to thermal expansion of the oceans (Houghton *et al.*, 1996) (figure 3). Mean rainfall over land has shown considerable variability across this century (figure 4), with a small positive global trend of about a 1% increase between 1900 and 1980 (Nicholls *et al.*, 1996), and a slight decline thereafter. Increased atmospheric carbon

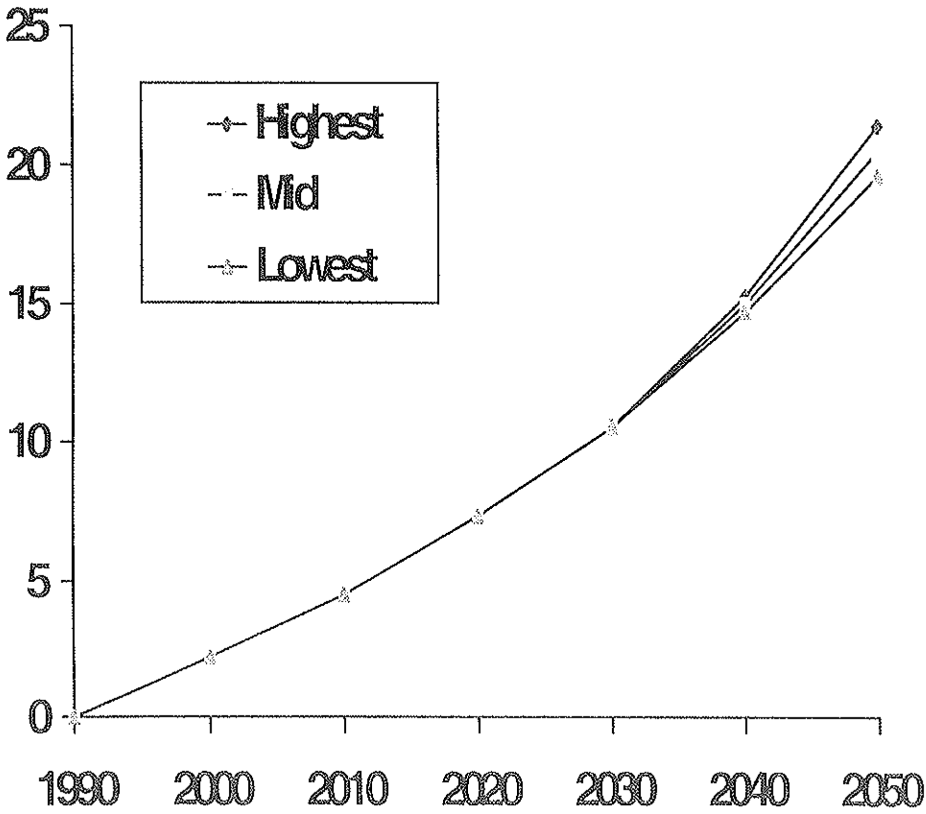

Fig. 3. Projected global mean sea level rise (highest, median and lowest predicted values), 1990-2050, the 1990 value set at zero. A climate sensitivity of 2.5 degrees celcius increase in global temperature is assumed for every doubling of atmospheric carbon dioxide concentration. Combined contribution of Greenland and Antarctic ice sheet melt is assumed to be low. Adapted from Houghton *et al.*, 1996.

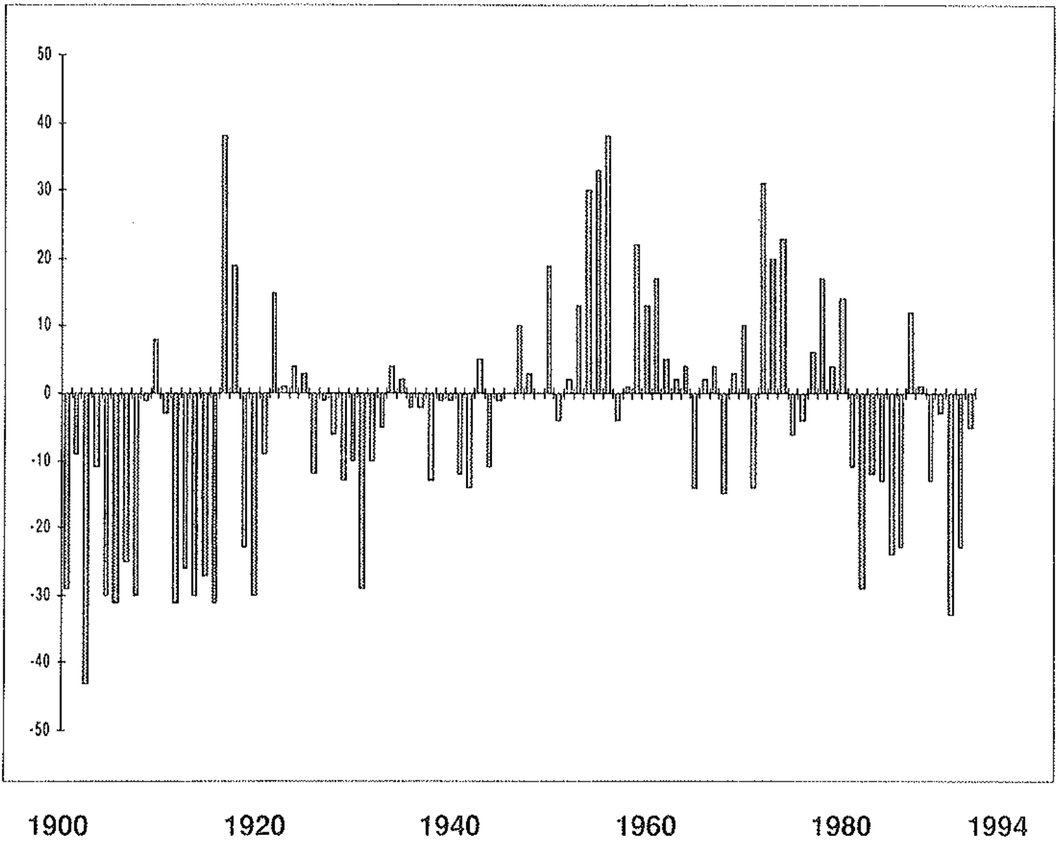

Fig. 4. Global rainfall variation, 1900-1994 (annual anomaly in millimeters from the mean value across this period). Adapted from Houghton *et al.*, 1996.

dioxide concentrations are projected to lead to an overall increase in global mean rainfall (Kattenberg *et al.*, 1996; Houghton *et al.*, 1996).

Changing rainfall patterns in the tropical regions of the world have been modelled by various authors (Colman *et al.*, 1995; Hasselman *et al.*, 1995; Mitchell *et al.*, 1995; Mitchell and Johns, 1996; Giorgi *et al.*, 1998). The distribution of this rainfall change is projected to be uneven, with December to February increases in mean rainfall in regions of northern Latin America, southern Africa and south-east Asia, and declines in other regions of Latin America, south-east Asia and New Guinea (Kattenberg *et al.*, 1996). This is projected to be accompanied by July to August increases in mean rainfall in other regions of northern Latin America, as well as Saharan Africa, the Horn of Africa and Arabia, as well as regions of south and south-east Asia (figure 5).

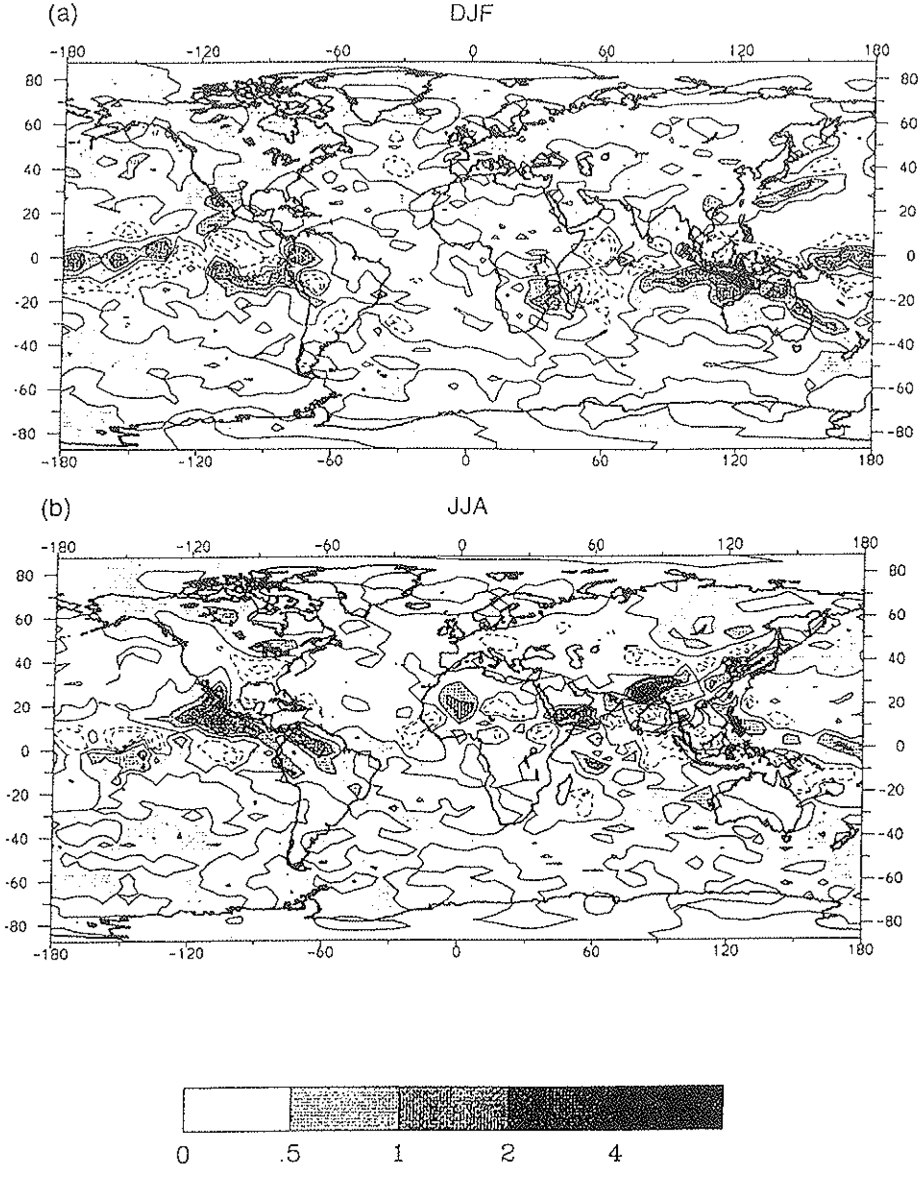

Fig. 5. Seasonal changes in rainfall by the year 2060, assuming a 1% per annum increase in atmospheric carbon dioxide concentration. Contours represent +/– 0.5, 1, 2, and 4 mm rainfall/day from a 1990 baseline. Areas of reduced rainfall are represented by dashed contours, while regions of increased rainfall are represented by shaded areas (modified from Colman *et al.*, 1995; Kattenberg *et al.*, 1996).

Heaviest overall rainfall increases are projected to occur in northern Latin America, as well as some central Pacific Islands. Heaviest rainfall increases during the months December to February alone are projected to occur in south-eastern Africa and Indonesia. Heaviest increases during the months June to August are projected to occur in west Saharan Africa, Arabia, northern regions of south Asia, the Philippines and parts of coastal China (Colman *et al.*, 1995; McLean *et al.*, 1998). Decline in overall rainfall is projected for the New Guinea Island, while declines in rainfall are projected for the months December to February in parts of Latin America and central Africa. Rainfall decline during the months June to August is projected for parts of coastal west Africa, east Saharan Africa and central Africa, India and parts of east and south-east Asia (Colman *et al.*, 1995).

Within season, rainfall variability is projected to increase, with greater likelihood of heavy rainfall events occurring more frequently (accompanied by an increase in numbers of dry days) as a consequence of increased concentrations of atmospheric carbon dioxide (Fowler and Hennessy, 1995; Gregory and Mitchell, 1995; Giorgi *et al.*, 1998; McLean *et al.*, 1998).

An additional factor impacting on rainfall and temperature variability in some parts of the developing world will continue to be the frequency, duration and intensity of El Niño events (Glantz, 1996; Canziani and Diaz, 1998). The El Niño Southern Oscillation phenomenon is the major source of generation of climate variability globally (Nicholls *et al.*, 1996). This creates warm climatic events on cycles of between 2 and 5 years (Glantz, 1996). The released latent heat associated with an El Niño event affects global temperature (Graham, 1995), while the oceanic upwelling characteristic of this phenomenon influences atmospheric carbon dioxide concentrations (Keeling *et al.*, 1989). The climatic consequences of El Niño include greater than average rainfall in parts of the west coast of Latin America, lower than average rainfall in south-east Asia and New Guinea, and warmer environmental temperatures than usual in areas of south and south-east Asia and New Guinea (figure 6). El Niño events have consequences for climate outside of the Pacific region, with higher rainfall in parts of central and east coast Latin America, and in parts of east Africa, as well as drier conditions in other parts of Latin America and in southern Africa (Ropelewski, 1992).

El Niño events took place more often around the beginning of the twentieth century than during the 1960s and 1970s (Anderson, 1992). However, El Niño periodicity has declined since the 1970s. Between 1965 and 1990, El Niño periodicity was about 4 years (Glantz, 1996), while in the period 1990-95, 3 El Niño events were observed (Glantz, 1996), with a fourth major El Niño event having taken place in 1997. The probability of

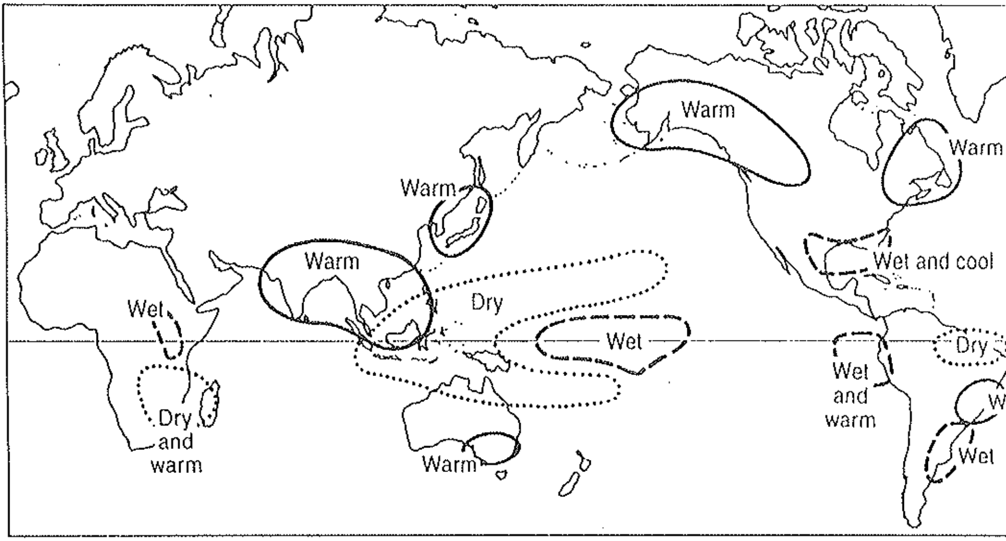

Fig. 6. Typical rainfall and temperature patterns associated with El Niño-Southern Oscillation conditions for the Northern Hemisphere autumn and winter seasons. From Ropelewski, 1992.

increased frequency of El Niño events into the first half of the twenty-first century is high, although unpredictable (Houghton *et al.*, 1996). However, it is not clear whether the frequency and intensity of such events would change with longer-term global warming (Canziani and Diaz, 1998). Since 1976/77 there have been fewer La Niña than El Niño events (Nicholls *et al.*, 1996). The former are cold events which have the opposite climatic impacts to El Niño events, and are generally favourable to agriculture.

POTENTIAL IMPACT OF CLIMATE CHANGE ON HUMAN ECOSYSTEMS

Most ecosystemic changes arising from climatic change are likely to have impact upon human populations. Terrestrial ecosystems and climate are closely coupled, and changing vegetation type and productivity according to changing temperature, rainfall, and atmospheric carbon dioxide production will enter feedback relationships (Melillo *et al.*, 1996), affecting agricultural and other subsistence practices. Increased temperatures and changing rainfall patterns will change the crop growth potential, as well as patterns of seasonality (Reilly, 1996; Zinyowera *et al.*, 1998). Furthermore, rising sea-level will result total inundation by water of many lands occupied by human populations (Warrick *et al.*, 1996; Bijlsma, 1996), who will then have to migrate in order to find a livelihood elsewhere. Table 1 shows the possible impact of projected average sea-level rise by the year 2050 on human populations in 7 developing countries for which good data for prediction is available. There is enormous variation by country and according to geography. A sea-level rise of 20 cm is projected to affect 14 million people in China, who would suffer coastal inundation of their lands. This represents 1.2% of the projected population in 2050, who would be enforced migrants as a result of flooding. In Bangladesh, the population projected to migrate due to coastal inundation by sea-level rise of 20 cm is 24.8 million, or 11.7% of the estimated 2050 population. For India, the values are 2.3 million, or 0.1% of the projected population. The social disruption associated with such change is incalculable.

The flexibility of subsistence systems to respond to seasonal uncertainty differs across societies (de Garine and Harrison, 1988), and is likely to vary according to the ability to generate food surpluses (Ulijaszek, 1995). Climate change is likely to increase seasonal uncertainty, and societies with flexible coping strategies already in place are likely to fare better than those without them. Economic factors will influence such flexibility, commercial-

Table 1. *Possible impact of projected global sea level rise by year 2050 on human populations in selected countries. Millions of people affected by unundation in 2050, projected from population trends using medium variant projecyion, 1960-2050* (United Nations Population Division, 1998), *and human impact models of sea level change* (China: Bilan, 1993, Han *et al.*, 1995; India: Pachauri, 1994; Bangladesh: Huq *et al.*, 1995; Nigeria: French *et al.*, 1995; Senegal: Dennis *et al.*, 1995; Benin: Adam, 1995; Venezuela: Volonte & Arismendi, 1995).

	Population		Popn affected by 20 cm sea level rise
	1998 (x10^6)	2050 (proj) (x10^6)	(x10^6)
China	1221	1478	17.3
India	934	1529	2.3
Bangladesh	118	212	24.8
Nigeria	99	244	13.8
Senegal	8	23	0.6
Benin	5	16	0.7
Venezuela	22	42	0.2

ized and technologically-oriented agricultural systems probably being more resilient than those relying on simpler technologies. Socioeconomic differences in resilience of subsistence production to seasonal uncertainty exist in the developing world (Messer, 1989), and these are likely to be amplified by increased uncertainty due to climate change. Adaptations in food crop production are likely to include the adoption of different crop species and varieties, the use of high-yielding varieties, and the extension of irrigation to new lands (Reilly, 1996). In most populations, these adaptations are likely to be mediated by socio-economic factors.

Slight increases in rainfall coupled with increased mean temperatures may result in increased crop productivity in many regions of the world, although increased temperature, rainfall and potential vegetation will be associated with greater rates of evaporation and evapotranspiration (Kirschbaum, 1996). Changing patterns of rainfall and temperature in some regions of the world are likely to influence both subsistence patterns and food production. Figures 7, 8 and 9 show areas of projected change in rainfall seasonality in Central and Latin America, Saharan and Sub-Saharan

Fig. 7. Areas of projected increased (+) rainfall seasonality, Central and Latin America, 2050.

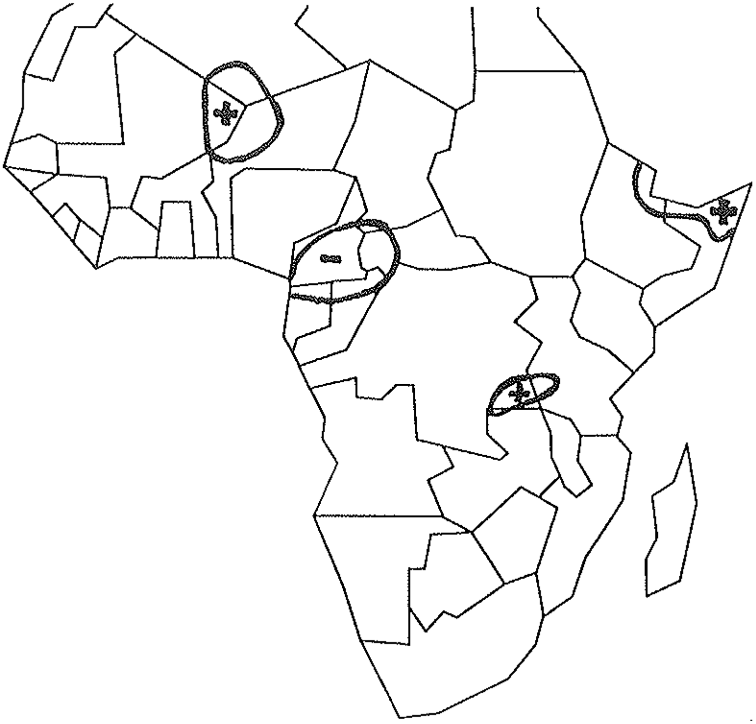

Fig. 8. Areas of projected increased (+) and decreased (–) rainfall seasonality, Saharan and Sub-Saharan Africa, 2050.

Africa, and Tropical Asia, respectively (Colman *et al.*, 1995), by the year 2050. Areas in which increased seasonality is projected include west central America, north-eastern inland Latin America, areas of the central Andes. west Saharan Africa, the Horn of Africa, and central Africa, Pakistan, northern India, Nepal, Bangladesh, Bhutan and Tibet, as well as inland China, Burma, Thailand, the Philippines and Indonesia. Reduced rainfall seasonality is projected for part of west and central Africa, including Cameroon.

The ways in which changing seasonal rainfall patterns may influence subsistence at local levels will be nested within regional and global patterns of climate change. Subsistence adaptations by local populations will involve responses to both local and regional climate including variation in the timing and intensity of rainy seasons, and extreme events such as flooding and/or drought. Local responses to changing climatic seasonality are likely to vary enormously, according to local ecology. For example, in Bangladesh, the availability of the main staple, rice, is highly seasonal. Although there are

Fig. 9. Areas of projected increased (+) rainfall seasonality, tropical Asia, 2050.

three rice harvests in Bangladesh, the main rice crop harvest (aman), which supplies about 60% of total rice production, takes place between November and mid-January, and the period September to October is known as the hungry season (Abdullah, 1989). Changes in absolute and seasonal rainfall patterns, and increased potential for extreme climatic events will increase the likelihood of flooding and other natural disasters. Any potential increase in the production potential of the smaller March to May, and June to August rice harvests due to increased winter rainfall may benefit the wealthier members of rural Bangladeshi society. Increased landlessness through dispossession due to flooding by rising sea-level, and changing needs for irrigation are likely to favour the better-off members of rural Bangladeshi communities, who may be better able to exploit the dispossessed as cheap labour, and to undertake changes of technology to adapt agriculture to new circumstances.

A different example of potential local response to changing rainfall seasonality comes from Burkina Faso, where millet and sorghum supply the vast majority of the dietary staple. An extended dry season traditionally precludes extensive cropping, and poor prediction of the onset of the rains can lead to crop failure (Annegers, 1973). A projected increased monthly rainfall of between 30 and 60 mm between June and August could significantly augment the short wet season to the extent that sorghum and millet yields could be raised, and the potential for limited maize cultivation increased. Slight rainfall during the current extensive dry season might allow the appearance of ephemeral grass according to unpredictable peaks of rainfall, much as it occurs already during the current short wet season (Bernus, 1988). This would allow improved grazing for herds of dairy animal belonging to pastoralists in this region of Africa, and perhaps increased potential for agro-pastoralism as a consequence of the slightly longer and more intense wet season. However, increased temperatures would be likely to increase evaporative loss from the soil to some unknown extent.

El Niño events are likely to disturb projected patterns of rainfall seasonality by changing rainfall and temperature cycles periodically, perhaps as often as once every 2-3 years. Figure 6 shows typical rainfall and temperature patterns associated with El Niño-Southern Oscillation conditions for the Northern Hemisphere autumn and winter seasons (Ropelewski, 1992). Under such circumstances it is likely to become more difficult to talk of regular seasonal patterns in some parts of the developing world. For example, in El Niño years, the elevated rainfall associated with global warming in the Philippines and Indonesia may be cancelled out by mild El Niño events, or replaced by drought during severe El Niño events. El Niño events may confound existing and relatively unchanging seasonal rainfall patterns in coastal northwest Latin America, while in east Africa seasonal rainfall may be confounded in El Niño years with a more extreme rainfall pattern. In southern Africa, seasonal rainfall may be reduced to unpredictable degrees. Local unpredictability of El Niño events and the rainfall patterns associated with them may have significant impact on subsistence food production.

IMPACTS ON GLOBAL FOOD PRODUCTION

Developing countries accounted for 80% of direct food consumption of cereals in 1981-94. The International Food Policy Research Institute's International Model for Policy Analysis of Agricultural Commodities and Trade predicts the demand for cereals as a function of prices, income, and population growth. Projected demand for cereals to the year 2020 is anticipated to come largely from increased crop yield, and secondarily from rather small increases in land available to crop growth (Rosegrant *et al.*, 1999). For developing countries, demand for all cereals is projected to increase by 60%

above the 1993 baseline by the year 2020, while for developed countries, demand is projected to increase by 14% above the 1993 value.

The projected impact of climate change on cereal production has been estimated by using models which incorporate factors that influence crop yield across seasons (Woodward, 1993), including plant response to climate, local limitations in water and nutrient availability (Leemans and Solomon, 1993; Reilly, 1996), carbon dioxide effects on water-use efficiency (Leuning *et al.*, 1993) as well as socio-economic responses to climatic predictability and change (Darwin *et al.*, 1995). Problems with predictive modelling of climate change include poor accuracy and reliability in projecting crop yields or their failure under extreme conditions, and poor reliability across different models in estimating the extent of yield change (Reilly *et al.*, 1994). Assumptions built into these models are inevitably simplifications of reality, since the interactions between climatic, agricultural and economic variables are too complex to model with any accuracy. Furthermore, the assumptions built into different models vary, and the extent to which quantitative estimates of crop yield change can be compared is limited. Thus, the projected potential food production change between the years 2000 and 2050 must be interpreted with caution.

Potential food production has been projected using a range of models which incorporate some or most of the following factors: 1) existing levels of output; 2) changing temperature, rainfall and atmospheric carbon dioxide concentrations; 3) changing seasonal temperature and rainfall patterns and the human responses to them; and 4) adaptation through changing cropping types and patterns, changing agricultural practices and the technologies associated with them. Studies modelling the potential effects of a doubling of present levels of atmospheric carbon dioxide on crop yields generally give mixed results, but project increased yields for C3 crops (most cereal crops except maize, millet and sorghum) of about 30% above present values (Reilly, 1996). With respect to optimal temperatures for growth, C3 crops prefer a range of 15 to 20°C, while C4 crops (maize, millet and sorghum) prefer a range of temperatures between 25 and 30°C. The projected reduction in diurnal variation in temperature with global warming might result in increased yields among crops growing in areas that are close to their temperature optima, because of potential prolonged exposure of crops during growth to optimal temperatures (Reilly, 1996). Consistent moisture availability is essential for optimal crop growth. Although increased rainfall is predicted, temperature increases may to lead to excess evaporative loss relative to rainfall in some regions but not others (Rosenzweig and Parry, 1994).

Table 2 gives projected changes in maize yields in the tropical world due to climate change from various modelling studies. Of the 12 studies presented, 11 project declines in yield. Only one study, that of Schulze *et*

Table 2. *Projected impact of climatic change in the tropical world on maize yields (+ increase; +/– either increase or decrease depending on forcing in model; – decrease)* (results of 13 modelling studies summarized from Reilly, 1996: Latin America: Liverman and O'Brien, 1991, Liverman *et al.*, 1994, Downing, 1992, Sala and Paruelo, 1994, Siquera *et al.*, 1994; Africa: Akong'a *et al.*, 1988, Downing, 1992, Schulze *et al.*, 1993, Eid, 1994, Muchena, 1994; Asia: Parry *et al.*, 1992, Qureshi and Hobbie, 1994).

	+	+/–	–
Latin America	1	0	4
Africa	1	0	4
Asia	0	0	3
All	2	0	11

al.. (1993) projects an increased yield for this crop, for South Africa. In general, maize will not benefit from increased atmospheric carbon dioxide concentrations, but may suffer from excessive soil moisture loss as a consequence of increasing temperatures (Reilly, 1996).

Wheat cultivation is common in large parts of the developing world, including India, Pakistan, Uruguay, Argentina and Brazil. Global demand for wheat is rising faster than for any other cereal staple (Rosegrant *et al.*, in press). Table 3 gives projected impacts of climatic change on wheat yields in tropical countries, from 8 modelling studies. Of these, 6 project decreased yield, while 2 studies project either an increase or decrease in yield accord-

Table 3. *Projected impact of climatic change in the tropical world on wheat yields (+ increase; +/– either increase or decrease depending on forcing in model; – decrease)* (results of 9 modelling studies summarized from Reilly, 1996: Latin America: Downing, 1992, Baethgen, 1994, Siquera *et al.*, 1994; Africa: Eid, 1994; Qureshi and Hobbie, 1994, Rosenzweig and Iglesias, 1994).

	+	+/–	–
Latin America	0	0	4
Africa	0	0	1
Asia	0	2	2
All	0	2	7

ing to the model type, the assumptions made and the variables entered in the modelling procedure. These latter 2 projections are based on data from India and Pakistan (Rosenzweig and Iglesias, 1994). However, other studies project declining yields of wheat for India and Pakistan (Qureshi and Hobbie, 1994), as well as for Latin America (Downing, 1992; Baethgen, 1994; Siquera *et al.*, 1994). Although increased atmospheric carbon dioxide concentration should favour increased wheat yields, the projected decline of this staple in regions of the tropical world may lie in the increasing global temperatures which move the cultivation of wheat away from it's optimal growth range, as well as the possible reversal of vernalization which can occur at temperatures above 30°C, and the severe loss of yield which comes as a consequence of this (Evans *et al.*, 1975).

Table 4 gives projected impacts of climatic change on rice yields. Of the 19 modelling studies, 3 project an increased yield, 9 project increase or decrease depending on assumptions applied in the model, and 7 project a decline in yield. The 3 that predict an increase include Bangladesh (Qureshi and Hobbie, 1994), Indonesia and Malaysia (Matthews *et al.*, 1994a). The 9 studies that project either increased or decreased yield include Bangladesh (Matthews *et al.*, 1994b; Rosenzweig and Iglesias, 1994), Thailand (Parry *et al.*, 1992; Matthews *et al.*, 1994b; Rosenzweig and Iglesias, 1994), Philippines (Matthews *et al.*, 1994b; Rosenzweig and Iglesias, 1994), India (Matthews *et al.*, 1994b), and Myanmar (Matthews *et al.*, 1994b). The studies that project a decreased yield due to climate change include Indonesia (Parry *et al.*, 1992; Qureshi and Hobbie, 1994), Malaysia (Parry *et al.*, 1992) the Philippines (Qureshi and Hobbie, 1994), Sri Lanka (Qureshi and Hobbie, 1994), and south China (Zhang, 1993; Jin *et al.*, 1994). In general,

Table 4. *Projected impact of climatic change in the tropical world on rice yields (+ increase; +/– either increase or decrease depending on forcing in model; – decrease)* (results of 19 modelling studies summarized from Reilly, 1996: no preductive modelling of wheat yields in Latin America or Africa; Asia: Parry *et al.*, 1992, Zhang, 1993, Jin *et al.*, 1994, Matthews *et al.*, 1994a,b, Qureshi and Hobbie, 1994, Rosenzweig and Iglesias, 1994).

	+	+/–	–
Latin America	0	0	0
Africa	0	0	0
Asia	3	9	7
All	3	9	7

rice yields should benefit from increasing concentrations of atmospheric carbon dioxide, although changing rainfall patterns are likely to influence overall yields differently across the region.

While projections of cereal yields give varied results according to assumptions made in the modelling procedure, changes in aggregate level of cereal production are likely to be small to moderate (Kane *et al.*, 1992; Fischer *et al.*, 1994; Reilly *et al.*, 1994; Rosenzweig and Parry, 1994). However, a potential disparity in production between tropical and temperate countries has been identified (Rosenzweig and Parry, 1994). Table 5 gives 3 sets of projections for crop production in the developing world, based on climate change scenarios which incorporate increased global temperature of between 2.5 and 5.2°C. All 3 models project reduced crop production of between 14% and 16% below baseline values (obtained by modelling without climatic forcing), under conditions of temperature and rainfall change only. The impact of increased atmospheric carbon dioxide levels on plant growth in addition to the impact of temperature and rainfall change is projected to result in crop production between 9% and 11% below baseline values. Fairly limited human behavioural adaptation to climate change, including changes in the crop varieties used, changes in time of planting by less than a month to accommodate changing rainfall seasonality, and changes in the extent of existing irrigation are projected to have little impact on crop production. However, behavioural adaptations involving changes in the types of crops grown, changes in planting dates by more

Table 5. *Projected change in cereals production in the developing world: 3 models. Per cent difference in 2060 from 1990 values* (adaptation 1: changes in crop variety & short planting date, extent of existing irrigation; adaptation 2: changes in crop type & long planting date, extension of irrigation into new areas; GFDL: Geophysical Fluid Dynamics Laboratory, USA; GISS: Goddard Institute for Space Studies, USA; UKMO: United Kingdom Meteorological Office) (adapted from Rosenweig & Parry, 1994).

Models:	GFDL	GISS	UKMO
Climate only	–13.7	–16.2	–16.3
+ CO_2 impact on plant growth	–9.2	–11.0	–10.9
+ Adaptation 1	–9.2	–11.2	–12.5
+ Adaptation 2	–5.6	–6.6	–5.8

Table 6. *Projected change in cereals production in the developing world: 3 models. Per cent difference in 2060 from 1990 values* (adaptation 1: changes in crop variety & short planting date, extent of existing irrigation; adaptation 2: changes in crop type & long planting date, extension of irrigation into new areas; GFDL: Geophysical Fluid Dynamics Laboratory; GISS: Goddard Institute for Space Studies; UKMO: United Kingdom Meteorological Office) (adapted from Rosenweig & Parry, 1994).

Models:	GFDL	GISS	UKMO
Climate only	–10.1	–3.9	–23.9
+ CO_2 impact on plant growth	5.2	11.3	–3.6
+ Adaptation 1	3.0	11.0	1.8
+ Adaptation 2	7.9	14.2	3.8

than one month (thus making large seasonal adjustments in agricultural practices), and the extension of irrigation into new areas, reduces the projected cereals production to about 6% below the baseline value.

Table 6 gives projections for crop production in the developed world, using the same conditions described for table 5. The rainfall and temperature change-only model projects declines in cereal production of between 4% and 24% relative to production projections using models which exclude climatic forcing. The incorporation of the potential physiological effect of increased atmospheric carbon dioxide concentration on plant growth within the rainfall and temperature change model brings projected production to between 4% below and 11% above projected baseline values (obtained by using the models which do not incorporate climatic forcing). Low-level behavioural adaptations including changes in crop varieties used, amount of water used in existing irrigation and small changes in planting date to accommodate changes in rainfall seasonality result in projected cereal production between 4% and 14% above the baseline values. More extensive behavioural adaptation, including changes in the types of crop grown, use of fertilizer, extensive changes in dates of planting to accommodate rainfall seasonality, and extension of irrigation to previously unirrigated areas leads to predicted yields which are between 2% and 11% above the baseline values.

Thus, while the potential impact of climate change on cereal production in the developing world is projected to be negative under all circumstances, in the developed world the impact of climate change is projected to be negative only when the effects of temperature and rainfall change are considered.

DISCUSSION

Although some of the events associated with climate change are likely to be catastrophic for significant numbers of people in the developing world, events will not proceed without attempts to buffer against. and adapt to, these changes. Adaptations in subsistence behaviour are likely to be foremost among these attempts. Increased temperature and changing rainfall patterns are likely to result in changing patterns of subsistence, which will involve attempts to ameliorate the extent of potential food source loss. These will be behaviour- and technology-driven, and will include changing crop types (including the use of cultivars that are either more drought resistant, water tolerant, with shorter cropping cycles, or any combination of these), the extent of irrigation, and the degree and type of fertilizer and pesticide use. However, the ability to undertake a number of these changes will be predicated upon access to resources and technology, and therefore those most likely to adapt are those with best access at present. Thus the existing gaps in socio-economic status currently found across rural communities and populations are likely to increase as a consequence of these changes, perhaps driven in some regions by repeated drought-related famine. Adaptations to climate change will involve greater risk-taking in the subsistence cycle. Those who are best placed to take risks are those who have best access to resources and technology, and are best buffered against food shortages. Thus it is likely that climatic uncertainty will increase the numbers exposed to seasonal hunger, and possibly famine, if climatic uncertainty results in failed harvests in repeated years.

Rising sea level will result in significant numbers having to leave their land because of inundation. Conservatively, the numbers are in the millions, while the worst case suggests that large proportions of the populations of low-lying countries with high rural population densities, such as Bangladesh, will have to migrate. If the worst case eventuates, then migrations equivalent to some of the largest seen in the twentieth century are to be expected during the twenty-first century. As largely impoverished and landless people, it is unlikely that such migrant populations will be assimilated as agricultural populations elsewhere. This is likely to consolidate the process of rapid urbanisation that is currently taking place in the developing world (Clark, 1996). Another significant change will be of potential tidal inundation of land currently not under such threat. Potential changes include seasonal inundation and potential crop loss, as well as salinification of currently arable land.

The impact of potentially very frequent El Niño events may reduce the certainty and predictability of seasonal rainfall in Asia, and parts of north-eastern Latin America, east and southern Africa. However, the extent to which El Niño events might change seasonal rainfall patterns is not clear. If an El Niño event brought rainfall levels back to those more typical of earlier times, then a tendancy of local populations not to adapt to changing seasonality would be easy to understand. However, the adaptive flexibility of rural populations should not be underestimated. Responses to changing patterns of seasonal rainfall traditionally involve adjustments to the subsistence cycle, initially by calling on adjustment strategies which are part of the existing suite of behavioural adaptations to nutritional and seasonal uncertainty (Ulijaszek and Strickland, 1993). Rural populations are usually acutely aware of rainfall variation and make sequential adjustments to time-honoured subsistence adaptations (World Bank, 1981). As the season develops, daily decisions are made, allowing adaptive responses to seasonal patterns that differ in detail from the average pattern (Watts, 1988). For agriculturalists, mixed cropping, sequential use of crop varieties, and control of the microclimate are all ways in which the potential effects of climatic uncertainty can be mitigated (Watts, 1988). At the extremes, seasonal migration and where it is possible, pastoralism, are adaptations to acute rainfall seasonality when the former strategies are not adequate (Bayliss-Smith, 1982). However, they may not be enough to prevent disaster if a dry season is prolonged and poorly predicted by local populations.

Projections of global cereal production do not take into account local responses to climatic uncertainty. However, while reduced crop production has been projected for the developing world, increased crop production is projected to be possible for the developed world. Thus, north-south disparities in wealth and resources are unlikely to be diminished as a consequence of changes in agricultural production due to climatic change alone.

REFERENCES

Abdullah, M. (1989): 'The Effect of Seasonality on Intrahousehold Food Distribution and Nutrition in Bangladesh', in *Seasonal Variability in Third World Agriculture*, ed. D.E. Sahn (Baltimore, Johns Hopkins University Press), pp. 57-65.

Adam, K.S. (1995): 'Vulnerability Assessment and Coastal Management Program in the Benin Coastal Zone', in *Preparing to Meet the Coastal Challenges of the 21st Century*, Volume 2. Proceedings of the World Coast Conference, Noordwijk, 1-5 November 1993 (The Hague, CZM-Centre Publication No. 4, Ministry of Transport, Public Works and Water Management), pp. 489-497.

Akong'a, J., Downing, T.E., Konijn, N.T., Mungai, D.N., Muturi, H.R., and Potter, H.L. (1988): 'The Effects of Climatic Variations on Agriculture in Central and Eastern Kenya', in *The Impact of Climatic Variations on Agriculture*. Volume 2, *Assessments in Semi-Arid Regions*, eds. M.L. Parry, T.R. Carter and N.T. Konijn (Dordrecht, Kluwer Academic Press), pp. 123-270.

Anderson, R.Y. (1992): 'Long-term Changes in the Frequency of Occurence of El Niño Events, in *El Niño: Historical and Paleoclimatic Aspects of the Southern Oscillation*, ed. H.F. Diaz and V. Markgraf (Cambridge, Cambridge University Press), pp. 193-200.

Angell, J.K. (1988): 'Variations and Trends in Tropospheric and Stratospheric Global Temperatures, 1958-87', *Journal of Climatology*, 1, pp. 1296-1313.

Annegers, J.F. (1973): 'Seasonal Food Shortages in West Africa', *Ecology of Food and Nutrition*, 2, pp. 251-257.

Arnell, N., Bates, B., Lang, H., Magnuson, J.J., and Mulholland, P. (1996): 'Hydrology and Freshwater Ecology', in *Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. R.T. Watson, M.C. Zinyowera and R.H. Moss (Cambridge, Cambridge University Press), pp. 325-363.

Baethgen, W.E. (1994): 'Impact of Climate Change on Barley in Uruguay: Yield Changes and Analysis of Nitrogen Management Systems', in *Implications of Climate Change for International Agriculture: Crop Modeling Study*, eds. C. Rosenzweig and A. Iglesias (Washington, United States Environmental Protection Agency), pp. 1-13.

Bayliss-Smith, T.P., *The Ecology of Agricultural Systems* (Cambridge, Cambridge University Press).

Bernus, E. (1988): 'Seasonality, Climatic Fluctuations, and Food Supplies (Sahelian nomadic pastoral societies)', in *Coping with Uncertainty in Food Supply*, eds. I. de Garine and G.A. Harrison (Oxford, Oxford University Press), pp. 318-336.

Bijlsma, L. (1996): 'Coastal Zones and Small Islands', in *Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. R.T. Watson, M.C. Zinyowera and R.H. Moss (Cambridge, Cambridge University Press), pp. 289-324.

Bilan, D. (1993): 'The Preliminary Vulnerability Assessment of the Chinese Coastal Zone Due to Sea Level Rise', in *Vulnerability Assessment to Sea Level Rise and Coastal Zone Management. Proceedings of the IPCC/WCC'93 Eastern Hemisphere Workshop, Tsukuba, 3-6 August, 1993*, eds. R. McLean and N. Mimura (Canberra, Australia, Department of Environment, Sport and Territories), pp. 177-188.

Canziani, O.F., and Diaz, S. (1998): 'Latin America', in *The Regional Impacts of Climate Change. An Assessment of Vulnerability*, eds. R.T. Watson, M.C. Zinyowera and R.H. Moss (Cambridge, Cambridge University Press), pp. 187-230.

Christy, J.R., and McNider, R.T. (1994): 'Satellite Greenhouse Warming', *Nature*, 367, p. 325.

Clark, D. (1996): *Urban World/Global City* (London, Routledge).

Colman, R.A., Power, S.B., MacAvaney, B.J., and Dahni, R.R. (1995): 'A Non-Flux-Corrected Transient CO_2 Experiment Using the BMRC Coupled Atmosphere/Ocean GCM', *Geophysics Research Letters*, 22, pp. 3047-3050.

Cubasch, U., Hegerl, G., Hellbach, A., Hock, H., Mikolajewicz, U., Santer, B.D., and Voss, R. (1995): 'A Climate Change Simulation Starting 1935'. *Climate Dynamics*, 8, pp. 55-69.

Darwin, R., Tsigas, M., Lewandrowski, J., and Raneses, A. (1995): *World Agriculture and Climate Change: Economic Adaptation. Report No. AER-709* (Washington, D.C., Economic Research Service).

Dennis, K.C., Niang-Diop, I., and Nicholls, R.J. (1995): 'Sea-Level Rise and Senegal: Potential Impacts and Consequences', *Journal of Coastal Research*, special issue 14, pp. 205-223.

Dickinson, R.E., Meleshko, V., Randall, D., Sarachik, E., Silva-Dias, P., and Slingo, A. (1996): 'Climate Processes', in *Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. J.T. Houghton, L.G. Meira Fiho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (Cambridge, Cambridge University Press), pp. 193-227.

Downing, T.E. (1992): 'Climate Change and Vulnerable Places: Global Food Security and Country Studies in Zimbabwe, Kenya, Senegal, and Chile', in *Research Report No. 1.* (Oxford, Environmental Change Unit, University of Oxford).

Eid, H.M. (1994): 'Impact of Climate Change on Simulated Wheat and Maize Yields in Egypt', in *Implications of Climate Change for International Agriculture: Crop Modeling Study*, eds. C. Rosenzweig and A. Iglesias (Washington, United States Environmental Protection Agency), pp. 1-14.

Evans, L.T., Wardlaw, I.F., and Fischer, R.A. (1975): 'Wheat', in *Crop Physiology*, ed. L.T. Evans (Cambridge, Cambridge University Press), pp. 101-149.

Fischer, G., Frohberg, K., Parry, M.L., and Rosenzweig, C. (1994): 'Climate Change and World Food Supply, Demand and Trade', *Global Environmental Change*, 4, pp. 7-23.

Fowler, A.M., and Hennessey, K.J. (1995): 'Potential Impacts of Global Warming on the Frequency and Magnitude of Heavy Precipitation', *Natural Hazards*, 11, pp. 283-303.

French, G.T., Awosika, L.F., and Ibe, C.E. (1995): 'Sea-Level Rise in Nigeria: Potential Impacts and Consequences', *Journal of Coastal Research*, special issue 14, pp. 224-242.

de Garine, I, and Harrison, G.A., (eds.) (1998): *Coping with Uncertainty in Food Supply* (Oxford, Oxford University Press).

Gates, W.L., Cubasch, U., Meehl, G.A., Mitchell, J.F.B., and Stouffer, R.J. (1993): 'An Intercomparison of Selected Features of the Control Climates Simulated by Coupled Ocean-Atmosphere General Circulation Models', in *World Climate Research Programme WCRP-82, WMO/TD No. 574* (Geneva, World Meteorological Organization).

Gates, W.L., Henderson-Sellers, A., Boer, G.J., Folland, C.K., Kitoh, A., McAvaney, B.J., Semazzi, F., Smith, N., Weaver, A.J., and Zeng, Q.-C. (1996): 'Climate Models-Evaluation', in *Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second*

Assessment Report of the Intergovernmental Panel on Climate Change, eds. J.T. Houghton, L.G. Meira Fiho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (Cambridge, Cambridge University Press), pp. 229-284.

Giorgi, F., Meehl, G.A., Kattenberg, A., Grassl, H., Mitchell, J.F.B., Stouffer, R.J., Tokioka, T., Weaver, A.J., and Wigley, T.M.L. (1998): 'Simulation of Regional Climate Change with Global Coupled Climate Models and Regional Modeling Techniques', in *The Regional Impacts of Climate Change. An Assessment of Vulnerability*, eds. R.T. Watson, M.C. Zinyowera and R.H. Moss (Cambridge, Cambridge University Press), pp. 427-437.

Glantz, M.H. (1996): *Currents of Change. El Niño's Impact on Climate and Society* (Cambridge, Cambridge University Press).

Graham, N.E. (1995): 'Simulation of Recent Global Temperature Trends', *Science*, 267, pp. 666-671.

Gregory, J.M., and Mitchell, J.F.B. (1995): 'Simulation of Daily Variability of Surface Temperature and Precipitation over Europe in the Current and 2 x CO_2 Climates using the UKMO Climate Model', *Quarterly Journal of the Royal Meteorological Society*, 121, pp. 1451-1476.

Han, M., Hou, J., and Wu, L. (1995): 'Potential Impacts of Sea-Level Rise on China's Coastal Environment and Cities: a National Assessment', *Journal of Coastal Research*, special issue 14, pp. 79-95.

Hansen, J.E., Wilson, H., Sato, M., Ruedy, R., Shah, K.P., and Hansen, E. (1995): 'Satellite and Surface Temperature Data At Odds?', *Climate Change*, 30, pp. 103-117.

Hasselmann, K., Bengtsson, L., Cubasch, U., Hegerl, G.C., Rodhe, H., Roeckner, E., von Storch, H., Voss, R., and Waszkewitz, J. (1995): 'Detection of Anthropogenic Climate Change Using a Fingerprint Method', in *Proceedings of 'Modern Dynamical Meteorology', Symposium in Honor of Aksel Wiin-Nielsen, 1995*, ed. P. Ditlevsen (ECMWF Press).

Henderson-Sellers, A. (1992): 'Continental Cloudiness Changes This Century', *Geological Journal*, 3, pp. 255-262.

Houghton, J.T., Jenkins, G.J., and Ephraums, J.J. (eds.) (1990): *Climate Change: The Intergovernmental Panel on Climate Change Scientific Assessment* (Cambridge, Cambridge University Press).

Houghton, J.T., Callander, B.A., and Varney, S.K. (eds.) (1992): *Climate Change 1992: The Supplementary Report to the Intergovernmental Panel on Climate Change Scientific Assessment* (Cambridge, Cambridge University Press).

Houghton, J.T., Meira Filho, L.G., Callander, B.A., Harris, N., Kattenberg, A., and Maskell, K. (eds.) (1996): *Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, Cambridge University Press).

Huq, S., Ali, S.I., and Rahman, A.A. (1995): 'Sea-Level Rise and Bangladesh: a Preliminary Analysis', *Journal of Coastal Research*, special issue 14, pp. 44-53.

Jin, Z., Daokou Ge, H.C., and Fang, J. (1994): 'Effects of Climate Change on Rice Production and Strategies for Adaptation in Southern China', in *Implications of Climate Change for International Agriculture: Crop Modeling Study*, eds. C. Rosenzweig and A. Iglesias (Washington, United States Environmental Protection Agency), pp. 1-24.

Jones, P.D. (1988): 'Hemispheric Surface Air Temperature Variations: Recent Trends and an Update to 1987', *Journal of Climate*, 1, pp. 654-660.

Jones, P.D. (1994), 'Hemispheric Surface Air Temperature Variations: a Reanalysis and an Update to 1993', *Journal of Climate*, 7, pp. 1794-1802.

Kane, S., Reilly, J., and Tobey, J. (1992): 'An Empirical Study of the Economic Effects of Climate Change on World Agriculture', *Climatic Change*, 21, pp. 17-35.

Kattenberg, A., Giorgi, F., Grassl, H., Meehl, G.A., Mitchell, J.F.B., Stouffer, R.J., Tokioka, T., Weaver, A.J., and Wigley, T.M.L. (1996): 'Climate Models - Projections of Future Climate', in *Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. J.T. Houghton, L.G. Meira Fiho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (Cambridge, Cambridge University Press), pp. 285-357.

Karl, T.R., Heim, R.R. Jr., and Quayle, R.G. (1991): 'The Greenhouse Effect in Central North America: If Not Now, When?', *Science*, 251, pp. 1058-1061.

Keeling, C.D., Bascastow, R.B., Carter, A.F., Piper, S.C., Wholf, T.P., Heimann, M., Mook, W.G., and Roeloffzen, H. (1989): 'A Three-Dimensional Model of Atmospheric CO_2 Transport Based on Observed Winds: Analysis of Observational Data, Aspects of Climate Variability in the Pacific and the Western Americas', *Geophysics Monographs*, 55, pp. 165-236.

Koeppen, W., and Gieger, R. (1936): *Handbuch der Klimatologie* (Berlin, Gebruder Borntraeger).

Kirschbaum, M.U.F. (1996): 'Ecophysiological, Ecological, and Soil Processes in Terrestrial Ecosystems: A Primer on General Concepts and Relationships', in *Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. R.T. Watson, M.C. Zinyowera and R.H. Moss (Cambridge, Cambridge University Press), pp. 57-74.

Leemans, R., and Solomon, A.M. (1993): 'Modeling the Potential Change in Yield and Distribution of the Earth's Crops Under a Warmed Climate', *Climate Research*, 3, pp. 481-508.

Leuning, R., Yang, Y.P., de Pury, D., Denmead, O.T., Dunin, F.X., Condon, A.G., Nonhebel, S., and Goudriaan, J. (1993): 'Growth and Water Use of Wheat Under Present and Future Levels of CO_2', *Journal of Agricultural Meteorology*, 48, pp. 807-810.

Liverman, D., and O'Brien, K. (1991): 'Global Warming and Climate Change in Mexico', *Global Environmental Change*, 1, pp. 351-364.

Liverman, D., Dilley, M., O'Brien, K., and Menchaca, L. (1994): 'Possible Impacts of Climate Change on Maize Yields in Mexico', in *Implications of Climate Change for International Agriculture: Crop Modeling Study*, eds. C. Rosenzweig and A. Iglesias (Washington, United States Environmental Protection Agency), pp. 1-14.

Matthews, R.B., Kropff, M.J., and Bachelet, D. (1994a): 'Climate Change and Rice Production in Asia', *Entwicklung und Landlicherraum*, 1, pp. 16-19.

Matthews, R.B., Kropff, M.J., Bachelet, D., and van Laar, H.H. (1994b): 'The Impact of Global Climate Change on Rice Production in Asia: a Simulation Study', in *Report No. ERL-COR-821* (Corvallis, Oregon, United States Environmental Protection Agency).

McLean, R.F., Sinha, S.K., Mirza, M.Q., and Lal, M. (1998): 'Tropical Asia', in *The Regional Impacts of Climate Change. An Assessment of Vulnerability*, eds. R.T. Watson, M.C. Zinyowera and R.H. Moss (Cambridge, Cambridge University Press), pp. 381-407.

Melillio, J.M., Prentice, I.C., Farquhar, G.D., Schulze, E.-D., and Sala, O.E. (1996): 'Terrestrial Biotic Responses to Environmental Change and Feedbacks to Climate', in *Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. J.T. Houghton, L.G. Meira Fiho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (Cambridge, Cambridge University Press), pp. 445-481.

Messer, E. (1989): 'Seasonality in Food Systems: An Anthropological Perspective on Household Food Security', in *Seasonal Variability in Third World Agriculture. The Consequences for Food Security*, ed. D.E. Sahn (Baltimore, The Johns Hopkins Press), pp. 151-175.

Mitchell, J.F.B., Davis, R.A., Ingram, W.J., and Senior, C.A. (1995): 'On Surface Temperature, Greenhouse Gases and Aerosols: Models and Observations', *Journal of Climate*, 10, pp. 2364-2386.

Mitchell, J.F.B., and Johns, T.J. (1996): 'Sensitivity of Regional and Seasonal Climate to Transient Forcing by CO_2 and Aerosols', *Journal of Climate.*

Muchena, P. (1994): 'Implications of Climate Change for Maize Yields in Zimbabwe', in *Implications of Climate Change for International Agriculture: Crop Modeling Study*, eds. C. Rosenzweig and A. Iglesias (Washington, United States Environmental Protection Agency), pp. 1-9.

Neilson, R.P. (1998): 'Simulated Changes in Vegetation Distribution under Global Warming', in *The Regional Impacts of Climate Change. An Assessment of Vulnerability*, eds. R.T. Watson, M.C. Zinyowera and R.H. Moss (Cambridge, Cambridge University Press), pp. 439-456.

Nicholls, N., Gruza, G.V., Jouzel, J., Karl, T.R., Ogallo, L.A., and Parker, D.E. (1996): 'Observed Climate Variability and Change', in *Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. J.T. Houghton, L.G. Meira Fiho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (Cambridge, Cambridge University Press), pp. 133-192.

Nieuwolt, K. (1977): *Tropical Climatology* (London, John Wiley and Sons).

Pachauri, R.K. (1994): *Climate Change in Asia: India* (Manila, Asian Development Bank).

Parry, M.L., Blantran de Rozari, M., Chong, A.L., and Panich, S. (1992): *The Potential Socio-Economic Effects of Climate Change in South-East Asia* (Nairobi, United Nations Environment Programme).

Qureshi, A., and Hobbie, D. (1994): *Climate Change in Asia: Thematic Overview* (Manila, Asian Development Bank).

Reilly, J. (1996): 'Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses', in *Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. R.T. Watson, M.C. Zinyowera and R.H. Moss (Cambridge, Cambridge University Press), pp. 427-467.

Reilly, J., Hohmann, N., and Kane, S. (1994): 'Climate Change and Agricultural Trade: Who Benefits, Who Loses?', *Global Environmental Change*, 4, pp. 24-36.

Ropelewski, C.F. (1992): 'Predicting El Niño events', *Nature*, 356, pp. 476-7.

Rosegrant, M.W., Leach, N., and Gerpacio, R.V. (1999): 'Alternative Futures for World Cereal and Meat Consumption', *Proceedings of the Nutrition Society*, 58, pp. 214-234.

Rosenzweig, C., and Iglesias, A. (eds.) (1994): *Implications of Climate Change for International Agriculture: Crop Modeling Study. EPA 230-B-94-003* (Washington, United States Environmental Protection Agency).

Rosenzweig, C., and Parry, M.L. (1994): 'Potential Impact of Climate Change on World Food Supply', *Nature*, 367, pp. 133-138.

Sala, O.E., and Paruelo, J.M. (1994): 'Impacts of Global Climate Change on Maize Production in Argentina', in *Implications of Climate Change for International Agriculture: Crop Modeling Study*, eds. C. Rosenzweig and A. Iglesias (Washington, United States Environmental Protection Agency), pp. 1-12.

Santer, B.D., Wigley, T.M.L., Barnett, T.P., and Anyamba, E. (1996): 'Detection of Climate Change and Attribution of Causes', in *Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. J.T. Houghton, L.G. Meira Fiho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (Cambridge, Cambridge University Press), pp. 407-443.

Schimel, D., Alves, D., Enting, I., Heimann, M., Joos, F., Raynaud, D., Wigley, T., Prather, M., Derwent, R., Ehhalt, D., Fraser, P., Sanhueza, E., Zhou, X., Jonas, P., Charlson, R., Rodhe, H., Sadasivan, S., Shine, K.P., Fouquart, Y., Ramaswamy, V., Solomon, S., Srinivasan, J., Albritton, D., Isaksen, I., Lal, M., and Wuebbles, D. (1996): 'Radiative Forcing of Climate Change', *Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. J.T. Houghton, L.G. Meira Fiho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (Cambridge, Cambridge University Press), pp. 65-131.

Schulze, R.E., Kiker, G.A., and Kunz, R.P. (1993): 'Global Climate Change and Agricultural Productivity in Southern Africa', *Global Environmental Change*, 4, pp. 329-349.

Siqueira, O.E. de, Boucas Farias, J.R., and Aguiar Sans, L.M. (1994): 'Potential Effects of Global Climate Change for Brazilian Agriculture: Applied Simulation Studies for Wheat, Maize, and Soybeans', in *Implications of Climate Change for International Agriculture: Crop Modeling Study*, eds. C. Rosenweig and A. Iglesias (Washington, United States Environmental Protection Agency), pp. 1-28.

Stouffer, R.J., Manabe, S., and Vinnikov, K.Y. (1994): 'Model Assessment of the Role of Natural Variability in Recent Global Warming', *Nature*, 367, pp. 634-636.

Trenberth, K.E., Houghton, J.T., and Meira Filho, L.G. (1996): 'The Climate System: an Overview', in *Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. J.T. Houghton, L.G. Meira Fiho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (Cambridge, Cambridge University Press), pp. 51-64.

Ulijaszek, S.J. (1995), *Human Energetics in Biological Anthropology* (Cambridge, Cambridge University Press).

Ulijaszek, S.J., and Strickland, S.S. (1993): *Nutritional Anthropology. Prospects and Perspectives* (London, Smith-Gordon).

United Nations Population Division (1998): *World Population Prospects: The 1998 Revision* (New York, United Nations).

Volonte, C.R., and Arismendi, J. (1995): 'Sea-Level Rise and Venezuela: Potential Impacts and Responses', *Journal of Coastal Research*, special issue 14, pp. 262-284.

Warrick, R.A., le Provost, C., Meier, M.F., Oerlemans, J., and Woodworth, P.L. (1996): 'Changes in Sea Level', *Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, eds. J.T. Houghton, L.G. Meira Fiho, B.A. Callander, N. Harris, A. Kattenberg and K. Maskell (Cambridge, Cambridge University Press), pp. 359-405.

Watson, R.T., Zinyowera, M.C., and Moss, R.H. (eds.) (1998): *Climate Change 1995. Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, Cambridge University Press).

Watts, M. (1988): 'Coping with the Market: Uncertainty and Food Security Among Hausa Peasants', in *Coping with Uncertainty in Food Supply*, eds. I. de Garine and G.A. Harrison (Oxford, Oxford University Press), pp. 260-289.

Winstanley, D. (1973): 'Recent Rainfall Trends in Africa, the Middle East, and India', *Nature*, 243, pp. 464-465.

Woodward, F.I. (1993): 'Leaf Responses to the Environment and Extrapolation to Larger Scales', in *Vegetation Dynamics and Global Change*, eds. A.M. Solomon and H.H. Shugart (New York, Chapman and Hall), pp. 71-100.

World Bank (1981): *Agricultural Technology Adoption in Northern Nigeria*, Volume 1 (Washington D.C., World Bank).

Zhang, H. (1993): *The Impact of Greenhouse Effect on Double Rice in China, Climate Change and Its Impact* (Beijing, Meteorology Press).

Zinyowera, M.C., Jallow, B.P., Shakespeare Maya, R., and Okoth-Ogendo, H.W.O. (1998): 'Africa', in *The Regional Impacts of Climate Change. An Assessment of Vulnerability*, eds. R.T. Watson, M.C. Zinyowera and R.H. Moss (Cambridge, Cambridge University Press), pp. 29-84.

THE NEEDS FOR FOOD — ENERGY AND PROTEIN

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In a paper on the "Mediterranean Diet", Ferro-Luzzi and James (1994) wrote: "... an understanding of human nutrition is a priority for agricultural scientists and policy makers since such an understanding is not simply for the 'public good' but a progenitor of potentially substantial agricultural changes". That precisely is the reason for including in this symposium a paper on human needs for energy and protein: if we can establish those needs accurately it would provide targets for those concerned with food production and distribution. Moreover, if a survey is made of people's intakes, it should be possible to diagnose those who are "malnourished", in that their intakes fall below their estimated requirements. Evidently the UN Agencies, and particularly the FAO, consider it useful for both these reasons to have information about human requirements, because for the last fifty years they have promoted discussions and sometimes research on this subject. Certainly it played an important part in the planning of rationing in Britain in World War II, but whether that example could be extended to the whole world in the twenty-first century is obviously highly problematic.

PROTEIN NEEDS

Protein Deficiency

Protein and energy have different functions in the body, but most diets and foods everywhere in the world, if eaten in sufficient amounts to cover energy needs, will also provide enough protein. It has therefore been difficult to identify specific effects of protein deficiency, separate from or additional to those of energy deficiency or starvation. The most striking effect is oedema, the accumulation of fluid all over the body. Oedema as a characteristic of famine was described by Thucydides (McCance, 1951). Skipping a couple of millennia, it occurred in the great Bengal famine of 1943, in the Bihar famines of 1965-66, and in the occupied countries of Europe during and after World War II. Now, as far as published accounts go, it is seen in adults mainly in the camps in Africa for refugees from famine and civil war (Collins, 1995). Oedematous malnutrition in children, known as kwashiorkor from the local name given to it by Williams (1935), a pioneer paediatrician working in Ghana, still occurs in many developing countries, although it is much less common than it used to be when I started work on the condition fifty years ago. At that time and throughout the sixties and seventies it was universally regarded as the result of protein deficiency, and from having been almost totally ignored up to the time of Williams' paper, came to be considered the commonest deficiency disease in the world. This led the UN, through its Protein Advisory Group, to invest much time and money in the development of high protein foods for young children. That waste of effort, for so it proved to be, could have been avoided if more attention had been paid to the real requirements of children for protein; it was not understood that whereas a diet providing 5% of its energy as protein is inadequate, 7-8% is enough and 20% entirely unnecessary. Nowadays a number of researchers contest the protein deficiency theory of nutritional oedema, but I myself believe that it is still substantially correct (Waterlow, 1984; 1992).

When it comes to diagnosing the presence and prevalence of lesser degrees of protein deficiency, in which oedema has not yet developed, we are in great difficulty, in both adults and children. In children growth is depressed, but this is a non-specific effect which could be the result of many kinds of deficiencies, and a different approach has to be used.

Protein requirements for health

In the last century the pioneers of research on protein metabolism, in seeking to define how much protein humans need, started at the other end: rather than concentrating on deficiency they tried to define adequacy. In the 1870s Voit in Germany proposed that the amount of protein needed by the average working man was about 120 g per day, i.e. for a man of average weight 1.7 g per kg (Carpenter, 1994). This estimate was based on his observations of what a German worker actually ate; he assumed that provided a man could afford it, he instinctively consumed what he needed. Voit was the great authority and his standard was widely accepted and used. For example, an economist called Nitti, writing in Naples in 1896, where the average worker consumed 70 g protein per day, wrote: "It is lack of albumen (protein) which renders them so idle, so apathetic and so absolutely degenerate" (Carpenter, 1994).

Voit's views, however, did not go uncontested. In the early years of this century Chittenden in the USA carried out long-term experiments on men and showed that they remained in good health on diets which provided only 50-60 g protein daily. In fact Chittenden, who lived on his diet for 7 years, concluded that his own health had never been better and he never felt fitter or more mentally active; he dismissed Voit's estimate as "leading to individual and racial suicide". Nevertheless, popular opinion in England traditionally supported Voit's view, as shown by this chauvinistic comparison by the novelist Thackeray between the English and the French: "I say to you (the reader) that you are better than a Frenchman. I would lay even money that you who are reading this are more than five feet seven (170 cm) in height and weigh eleven stone (70 kg), while a Frenchman is five feet four (162 cm) and does not weigh nine stone (57 kg). A Frenchman has after his soup a dish of vegetables, where you have one of meat". (It must be remembered, however, that this was written not that long after the Napoleonic war.)

In the same vein, in 1912 McCay, a Professor of Physiology in Calcutta, contrasted the physique and energy of the Sikhs, whose staple diet is wheat plus plenty of milk and meat, with that of the Bengalis, whose staple is rice with little animal protein, and whom he described as lethargic and incapable of a full day's work. Unfortunately these criteria, such as health, fitness and physical activity, though clearly very important, are undefined and subjective. Even in Voit's time it was realized that an *objective* criterion of the protein requirement is the minimum amount of protein needed to secure nitrogen balance. There is an obligatory daily loss of nitrogen from the body which cannot be repressed or reduced. This is the reason why even an adult who is not growing needs a regular supply of protein. The minimum requirement is the smallest intake of protein that will balance this loss. Balance can be achieved at any intake, within reason, above this minimum, the surplus being simply excreted. Both Voit's colleagues and Chittenden attempted to make measurements of nitrogen balance, but they did not realize that when a subject changes his nitrogen intake it takes 7-10 days to come into balance at the new level. Thus if one changed from a high Voit intake to a low Chittenden intake and measured N loss over only 3 days, the results would inevitably show a negative N balance, leading to the conclusion that the lower intake was inadequate, but this conclusion would be incorrect.

In the last few decades systematic studies of protein requirements by the nitrogen balance method have been made, mainly in the USA and some in India. In principle the procedure is simple, in practice laborious and expensive. Diets containing varying amount of protein, but otherwise equivalent, are fed until the level is found which just matches the obligatory loss.

Table 1. *Summary of safe level of protein intake.*

	g/kg/d
Infant, 1 month	2.35
Infant, 1 year	1.0
Boy, 12 years	0.9
Adult, both sexes	0.75
Elderly	1.0 (?)

From FAO/WHO/UNU, 1985.

Each diet must be fed for some 10 days to allow for adaptation. There is a good deal of scatter round the point of balance and therefore a margin of safety (two standard deviations) is added to give a value for the *safe level of intake*. The same procedure can be applied to children, with an extra allowance for growth, which becomes very small after the age of 2 years. The current figure for the safe level for adults of both sexes is 0.75 g protein per kg per day, or about 50 g for a 70 kg man (table 1). By this criterion Chittenden has prevailed over Voit.

The average nitrogen or protein requirement is always greater than the obligatory loss. This is because the body does not handle food proteins with 100% efficiency even when the protein is of high biological value (BV), like that of meat or milk. The BV depends on the amino acid composition of the protein; meat and milk have a high BV because their composition is close to that of the proteins of the human body. Vegetable proteins, on the other hand, are deficient in one or other essential amino acids, and the estimate of requirement has to be corrected for this. Modern methods of analysis of the composition of proteins in the diet make it possible to calculate a score for any protein or mixture of proteins. Thus if the score for meat is taken as 1.0, that for a vegetable protein mixture might be 0.7. The corrected requirement, in terms of the vegetable protein mixture, then becomes 0.75/0.7 = 1.1 g per kg per day.

Another way of looking at the protein requirement is to relate it to the energy intake from the food or diet. We can ask: will the diet meet the protein requirement if consumed in an amount that satisfies the appetite and meets the energy requirement? Some time ago it was suggested in the UK that a diet could be considered adequate if 10% of its energy was derived from protein; this is the P/E ratio. That was a useful rule-of-thumb approach for assessing the results of dietary surveys in Western countries; in fact most of our diets have a P/E ratio of 14-15%, so there is a large margin of safety, enough to cover wide variations in protein quality. However, in developing countries the P/E ratio may fall below 10%, and if most of the protein is derived from vegetable sources the composition of the protein could become critical, especially for children.

For accurate application of the method of scoring for protein quality mentioned above we need to know the human requirement for each essential amino acid. Balance studies carried out in the USA many years ago with pure amino acid mixtures (Rose, 1957) led to the conclusion that for adults there was no diet anywhere in the world where any essential amino acid was limiting; in other words, for adults quality is not a problem. However, just at the time when the UN Agencies had reached this conclusion (FAO/WHO/UNU, 1985) Young at MIT was developing a new method for determining amino acid requirements, based on the labelling of amino acids with a stable isotope of carbon, called the carbon-balance method (Young *et al.*, 1989). On the basis of this work Young suggests that the requirement for the essential amino acid lysine is substantially greater than had previously been thought. The lysine content is low in cereal proteins and since cereals form a large part of the diet in developing countries, Young's work suggests that large numbers of people may be at risk of deficiency of lysine. The problem has not yet been solved; it is one of the growing points in nutritional science at the present time, and it is obviously very important that it should be solved.

ENERGY NEEDS

The definition of energy requirements differs in an important way from that of protein requirements. With protein the aim is to find the *minimum* requirement or safe level necessary for health; higher intakes, within reason, are also safe, because excess protein is oxidized and excreted. With energy, by contrast, for any individual there is only one level of requirement, the intake that just balances the energy output. Any continuing excess is far from harmless, since it will be stored as adipose tissue and lead to obesity. How the normal person who neither gains nor loses weight over many years succeeds in matching input to output with such phenomenal accuracy is still a mystery, in spite of enormous amounts of research.

From the time of Voit (1870s) down to the League of Nations Health Organization (1937), various committees produced estimates of energy (calorie) requirements which were all very similar, about 3000 net calories per day, based on observations of what people in Western countries actually ate, just as Voit did for protein. After the War FAO produced its first report on Calorie Requirements in 1950, with progressively revised versions in 1957 and 1973. In these reports the estimates were based on a "reference" man or woman of a given age and body weight and engaged in moderate activity. The reference person was between 25 and 40 years old; the man weighed 65 kg and the woman 55 kg. The man's needs were assessed at 3000 kcal per day and the woman's at 2200. The derivation of these figures is not clear; the 1973 report simply says that "studies on energy expenditure and food intake show that these amounts adequately cover the average energy expenditure of these reference persons". These basal values were then adjusted for different body weights and levels of physical activity. For weight the committee seems to have assumed that the requirement per kg of the reference person could be applied over the whole range of body weights by simply using the reference value for kcals per kg. It was later shown that this is not correct. For calculating the expenditure at greater or lesser levels of physical activity the committee had available experimental measurements made by Durnin and Passmore (1955) of the energy costs of a wide range of activities.

Energy needs based on energy expenditure

The latest report in the series, FAO/WHO/UNU (1985) took a further step towards greater precision. It was recognized that the greater part of almost everyone's energy expenditure is taken up by the basal metabolic rate (BMR), that is, the sum of the energy costs of all the vital processes which keep the body going, measured in the resting and fasting state. Therefore a collection was organized of all reliable measurements of BMR in the world literature, some 7500 in all (Schofield *et al.*, 1985). Since the BMR is dependent on the body weight, although not, as assumed by previous committees, in a constant way, linear[1] equations were derived for relating BMR to weight in males and females over 6 different age-ranges (table 2). [When I was originally drafting this part of the report I tried to follow Shakespeare's seven ages of man, but this was not allowed by the WHO editors]. Since the original compilation the database has been enlarged to more than 10,000, with slight alterations in the equations, but the principle remains (Henry and

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[1] A polynomial or other complex expression can be derived to fit the BMR values over the whole range of weight from infancy to old age in a single equation, but this was considered too difficult to use. It also seemed more appropriate for each physiological state to have its own equation. The linear equations should not be projected beyond the data on which they are based. They should be regarded as segments of a curve.

Table 2. *Linear prediction equations of BMR from body weight (males).*

Age range	0 - 3y	61 W - 54 kcal
	3 - 10	22.7 W + 495
	10 - 18	17.5 W + 651
	18 - 30	15.3 W + 679
	30 - 60	11.6 W + 879
	60 +	13.5 W + 487

From Schofield *et al.*, 1985.

Rees, 1991). As before, an allowance has also to be made for physical activity. If the duration of different activities in the course of a day is determined and the cost of them taken from tables such as those of Durnin and Passmore (1955), the total energy expenditure on physical activities can be calculated. Most activities primarily involve moving the body, so that as an approximation their cost can be related to the body weight and added to the BMR to give a physical activity level (PAL). In practice the sum of most people's activities throughout the day can be classified simply as light, medium and heavy (table 3). The outcome of all this is that for any individual, the total energy expenditure, and hence the requirement, can be calculated with reasonable accuracy if we know his or her age, gender, body weight and life-style. Two examples are shown in table 4. The same can be done for a group if we know its age and sex composition and can estimate roughly the average weight and level of physical activity. In developing countries an extra allowance has to be made for children who are underweight as a result of malnutrition and infection, so that they can catch up to normal weight. The details of the application of this approach to populations have been well set out by James and Schofield (1990).

Table 3. *Average daily total energy expenditure expressed as multiples of BMR.*

	Activity		
	Light	Moderate	Heavy
Men	1.55	1.78	2.10
Women	1.56	1.64	1.82

From FAO/WHO/UNU, 1985.

Table 4. *Energy expenditure on two different life-styles.*

	Western office worker	Developing country farmer
Height, m	1.8	1.65
Weight, kg	75	55
BMI, kg/m²	23	20
BMR, kcal/d	1830	1530
PAL, x BMR	1.65	2.0
Total, kcal/d	3020	3040

An interesting point arose from the variation in BMR at any given body weight, which is of the order of ± 10%. This led to the suggestion (Sukhatme and Margen, 1982) that perhaps a person's BMR can adapt within this range to increases or decreases in food intake, and serious controversy raged for several years. However, Soares and Shetty (1987) in India and Friis Anderson *et al.* (1991) in Denmark showed that an individual's BMR remained constant over days, weeks, even months. It was also shown that differences in BMR between subjects could be explained almost entirely by differences in body composition – in the proportions of adipose and lean tissue, and within the lean differences in the pattern of organs and tissues with low or high metabolic rates (Garby and Lammert, 1994). If account is taken of these factors, the inter-individual variability falls to a very low level. It seems that the BMR must be regarded as a biological process that proceeds at a fixed rate, determined by the size and composition of the body. In the original analysis of BMR data it appeared that the BMR of people in developing countries were about 7% lower than the Western rates, but in more recent analyses this difference has disappeared (Ferro-Luzzi *et al.*, 1997).

Other criteria of protein and energy requirements

A critic may say: these calculations are all very well, but the approaches that have been described for defining the requirements for both protein and energy are based on the *status quo*, the actual body weight; they are not necessarily the requirements for a healthy and fully active life. The point is well taken. It is a necessary criterion of the requirement being met that a person should be in balance, both of protein and energy, but that alone is not enough. The intakes should also allow for the maintenance of an "acceptable" body weight, so here we come to the difficulty of defining what is "acceptable".

To be meaningful body weights have to be normalized for height. Obviously a short person will usually have a lower weight than a tall one. Normalization is achieved by the body mass index (BMI = Wt/Ht^2). A tabulation of BMI, based on general experience, is shown in table 5 (James *et al.*, 1988). We are not concerned here with the top end of the range – overweight and obesity. The normal part of the range, based originally on British soldiers, fit and in good health, is quite wide. Even towards the bottom of the scale the people must have been in energy and nitrogen balance, otherwise they would not have survived. Soares *et al.* (1991) studied a group of poor Indian labourers with an average BMI of 17. The BMR and the rate of whole body protein turnover were well preserved; most of the deficit in weight, compared to controls with higher BMI, was in their muscle mass, which means a reduced capacity for physical work. Other functional deficits have been described in association with a low BMI: in pregnant women a higher incidence of low birth-weight babies (Kusin *et al.*, 1994); in Bangladeshi men more time off work from infections and accidents (Pryer, 1993); in anorexic women a higher incidence of infections, etc. At the present time a great deal of research is going on to determine at what point in the BMI scale the risk of functional deficits becomes more than negligible, and so to improve the definition of malnutrition or undernutrition (James and Ralph, 1994). It will probably not be possible to find a cut-off point that can be applied universally; there are functions of which we in the West do not take much account. For instance, the well-known "starving Buddha" had presumably come down to a very low BMI on purpose to achieve a mystical state.

Table 5. *Interpretation of Body Mass Index.*

30	obese
30-25	overweight
25-18.5	acceptable
18.5-17	risk of undernutrition
17-16	moderate undernutrition
16	severe undernutrition
14	anorexia nervosa
13	refugees
12	risk of death

From James *et al.* (1998) and Collins (1995).

A final important point about low BMI is the duration of the undernutrition that has brought it about. Shetty's Indian labourers, with a BMI of 17, had presumably been undernourished all their lives, but their vital functions were well maintained and they were living lives that, for their environment, were more or less normal. By contrast, the subjects of Keys' wartime study in America, who had undergone voluntary starvation, at the end of 6 months, which is a short period in the life of a man, were in a state of physiological and psychological collapse (Keys *et al.*, 1950).

The BMI is proving to be a very useful tool. At present, statements by UNDP and FAO that so many million people in the world are undernourished or "hungry" are based on quite complicated estimates of intake, which are then compared with requirements. If agreement could be reached on the acceptable lower limit of BMI, the number of undernourished could be determined more plausibly from representative surveys of BMI, on the same principle as that used by WHO for estimating the prevalence of undernutrition in children (de Onis and Blössner, 1997). Another application gives some indication of the nature of the problem: if children are malnourished and the mother has a low BMI, the problem is probably one of food availability; if the children are undernourished but the mother has a BMI in the acceptable range, attention should be concentrated on public health measures and maternal education (James *et al.*, 1999). Thus, by bringing in the concept of a range of acceptable BMI, it is possible to supplement, in a practical way, the physiological definitions of energy and protein requirement.

The importance of stature

Lastly, it is necessary to consider stature, which is determined by the interplay between genes and environment. Historically, the average height of working-class men has varied with changes in socio-economic conditions (Floud *et al.*, 1990). In developing countries all over the world the heights of children from poor families are substantially less than those from rich families (Martorell, 1985). The full genetic potential for growth is repressed and nutritional factors probably play a large part in this. The effect on growth begins within a few months of birth (Waterlow, 1988; Waterlow & Schürch, 1994) and continues throughout infancy and early childhood. A study in India (Satyanarayana *et al.*, 1986) found that poor children at the age of 5 were 15 cm shorter than their better-off peers; between the ages of 5 and 18 both groups gained the same amount of height, so that in their deprived circumstances the poor children were able to grow normally but not to catch up, and their height deficit persisted into adult life. A number of studies have shown that providing extra food, particularly milk, to these stunted children can produce an increased growth in height. An early experiment was stimulated by Boyd Orr, the founding father of FAO, in the 1930s. In those years of the great depression people in England could not afford to buy milk, and the farmers were facing ruin. Boyd Orr arranged for the government to buy the surplus milk and to distribute it in schools. It is perhaps worth noting, in the light of today's Common Agricultural Policy, that the primary objective was to improve the standard of living of the farmers, not to improve the health of children. Be that as it may, the extra milk not only produced an increased growth in height; the teachers reported that the supplemented children were more active and difficult to control, as healthy children should be. Similar results from supplementation have been obtained in more recent studies (see Waterlow, 1992; Golden, 1994).

In the past, calculations of the protein requirements of children have been made in terms of the amounts needed to secure normal growth in body weight. The criterion of growth in height has been ignored. We do not know exactly what it is that is inadequate in the diets of children who are becoming stunted – whether it is animal protein or a particular amino acid, trace element or vitamin. In a large three-country study (Mexico, Kenya and Egypt) supported by the USAID, associations were found between the consumption of animal products, milk and meat, and height growth (Sigman *et al.*, 1998), but it was not possible to pinpoint the missing nutrient(s) more closely than that.

What does it matter to be short and small? Some of the ablest people in history, for example Napoleon, have been very short. It matters when the cause of being short is that genetic potential has not been fulfilled. It matters because nutritional stunting of physical growth is accompanied by retardation of mental development, particularly of cognitive function, as described by Grantham-McGregor in the study week 4 years ago (Grantham-McGregor, 1996) and by many others (see Walker *et al.*, 1998). The biological mechanism of this association is not known, but it is reasonable to suppose that even if the harmful effect operates only for a short time during the growing period, it will affect school achievement and future careers; to use a fashionable term, it will limit the development of human capital. Whether the retardation, once established, is recoverable in a favourable environment is not yet certain, because the studies have to be extended over so many years. A study in Guatemala begun 30 years ago, in which supplements were given for several years to children under 5 has provided some evidence that the beneficial effects on mental performance may have extended into adolescence and adult life (Pollitt *et al.*, 1995).

In conclusion, from the point of view of policy it will not be enough to concentrate on raising the production of cereal crops to meet the needs of the increased world population. It is a serious matter that concentration on cereals has led to a fall in the production of legumes, and a rise in their price (Gopalan, in press). Legumes are high in protein and complement the relatively low levels in cereals, particularly rice; thus they play an important part in improving the quality of the food available for young children. This should have a high priory in agricultural policy, in order to prevent the loss of human capital that results from early childhood malnutrition.

For both Voit and Chittenden it was an important criterion of energy and protein requirements that they should support an active and healthy life. Since their day there has been a tendency among nutrition scientists to concentrate on numbers and the precision with which requirements can be predicted. Now the wheel has turned back a little and our objective must be to define in a realistic way the qualities that make up a healthy and active life.

REFERENCES

Carpenter, K.J. (1994): *Protein and Energy: a Study of Changing Ideas in Nutrition* (Cambridge Univ. Press).

Collins, S. (1995): 'The Limit of Human Adaption to Starvation', *Nature Medicine*, 1, pp. 810-814.

Durnin, J.V.G.A., and Passmore, R. (1955): 'Human Energy Expenditure', *Physiological Reviews*, 35, pp. 801-840.

Food and Agriculture Organization (1950): 'Report of the Committee on Calorie Requirements', *FAO Nutritional Studies no. 5* (Rome, FAO).

— (1957): 'Calorie Requirements: Report of Second Committee on Calorie Requirements', *FAO Nutritional Studies no.15* (Rome, FAO).

Food and Agriculture Organization/World Health Organization (1973): 'Energy and Protein Requirements: Report of a Joint FAO/WHO ad hoc Expert Committee', *FAO Nutrition Meetings Report Series no. 52.*

FAO/WHO/UNU (1985): 'Energy and Protein Requirements: Report of an Expert Consultation', *WHO Technical Report Series no. 724* (Geneva, WHO).

Ferro-Luzzi, A., and James, W.P.T. (1994): 'The Mediterranean Diet: the Past and the Present but what for the Future?', in *Proceedings of Meeting on Agriculture and Human Health*, ed. P.H. Kouhoulakis (The Hague, Euragri), pp. 79-124.

Ferro-Luzzi, A., Petracchi, C., Kuriyan, R., and Kurpad, A.V. (1997): 'Basal Metabolism of Weight-stable Chronically Undernourished Men and Women: Lack of Metabolism Adaptation and Ethnic Difference', *American Journal of Clilnical Nutrition*, 66, pp. 1086-1093.

Floud, R.C., Wachter, K.W., and Gregory, A.S. (1990): *Height, Health and History: Nutritional Status in the United Kingdom 1750-1980* (Cambridge University Press).

Friis Anderson, M., Garby L., and Lammert, O. (1991): 'Within-subjects Variation over 10 months in 24h Energy Expenditure at a Fixed Physical Activity Programme', *European Journal of Clinical Nutrition*, 45, pp. 353-356.

Garby, L., and Lammert, O. (1994): 'Between-subjects Variation in Energy Expenditure: Estimation of the Effect of Variation in Organ Size', *European Journal of Clinical Nutrition*, 48, pp. 376-377.

Golden, M.H.N. (1994): 'Is Complete Catch-up Possible for Stunted Malnourished Children?', *European Journal of Clinical Nutrition*, 48, pp. 558-571.

Grantham-McGregor, S. (1996): 'Malnutrition and Human Development', in *Resources and Population*, eds. B. Colombo, P. Demery and Max Perutz (Oxford, Clarendon Press), pp. 233-250.

Henry, C.J.K., and Rees, D.G. (1991): 'New Predictive Equations for the Estimation of Basal Metabolic Rate in Tropical Peoples', *European Journal of Clinical Nutrition*, 45, pp. 177-185.

James, W.P.T., Ferro-Luzzi, A., and Waterlow, J.C. (1988): 'Definition of Chronic Energy Deficiency in Adults', *Human Nutrition: Clinical Nutrition*, 36C, pp. 331-336.

James, W.P.T., Ferro-Luzzi, A., Sette, S., and Mascie-Taylor, C.G.N., 'The Potential Use of Maternal Size in Priority Setting when Combating Childhood Malnutrition', *European Journal of Clinical Nutrition*, 53, pp. 112-119.

James, W.P.T., and Ralph, A. (eds.) (1994): 'The Functional Significance of Low Body Mass Index (BMI)', *European Journal of Clinical Nutrition*, 48, pp. S1-S202.

James, W.P.T., and Schofield, E.C. (1990): *Human Energy Requirements* (New York, FAO and Oxford University Press).

Keys, A., Brozek, J., Henschel, A., Michelson, O., and Taylor, H.L. (1950): *The Biology of Human Starvation* (Minneapolis, University of Minnesota Press).

Kusin, J.A., Kardjati, S., and Renqvist, U.H. (1994): 'Maternal Body Mass Index: the Functional Significance during Reproduction', *European Journal of Clinical Nutrition*, 48, Suppl 3, pp. S56-S67.

Martorell, R. (1985): 'Child Growth Retardation: a Discussion of its Causes and of its Relationship to Health', *Nutritional Adaptation in Man*, eds. K.L. Blaxter and J.C. Waterlow (London, John Libbey), pp. 13-30.

McCance, R.A. (1951): 'The History, Significance and Aetiology of Hunger Oedema', in *Studies of Undernutrition, Wuppertal, 1946-9*, Medical Research Council Special Reports Series no. 275 (London, H.M.S.O.), pp. 21-82.

de Onis, M., and Blössner, M. (1997): *WHO Global Database on Child Growth and Malnutrition* (Geneva, World Health Organization).

Pollitt, E., Gorman, K.S., Engle, P.L., Rivera, J.A., and Martorell, R. (1995): 'Nutrition in Early Life and the Fulfilment of Intellectual Potential', *Journal of Nutrition*, 125, pp. 1111S-1118S.

Pryer, J. (1993): 'Body Mass Index and Work Disabling Morbidity: Results from a Bangladeshi Case Study', *European Journal of Clinical Nutrition*, 47, pp. 653-657.

Rose, W.C. (1957): 'The Amino Acid Requirements of Adult Man', *Nutrition Abstracts and Reviews*, 27, pp. 631-647.

Satyanarayana, K., Prasanna Krishna, T., and Narasinga Rao, B.S. (1986): 'Effect of Early Childhood Malnutrition and Child Labour on Growth and Adult Nutritional Studies of Rural Indian Boys around Hyderabad', *Human Nutrition: Clinical Nutrition*, 40C, pp. 131-139.

Schofield, W.N., Schofield, C., and James, W.P.T. (1985): 'Basal Metabolic Rate – Review and Prediction, together with an Annotated Bibliography of Source Material', *Human Nutrition: Clinical Nutrition*, Suppl. 1, pp. 1-96.

Sigman, M., Espinosa, M.P., and Whaley, S.E. (1998): 'Mild Malnutrition and the Cognitive Development of Kenyan Schoolchildren', in *Nutrition, Health and Child Development* (Washington D.C., Pan American Health Organization) Scientific Publication No. 566, pp. 91-103.

Soares, M.J., and Shetty, P.S. (1987): 'Long-term Stability of Metabolic Rates in Young Adult Males', *Human Nutrition: Clinical Nutrition*, 41C, pp. 287-290.

Soares, M.J., Piers, L.S., Shetty, P.S., Robinson, S., Jackson, A.A., and Waterlow, J.C. (1991): 'Basal Metabolic Rate, Body Composition and Whole Body Protein Turnover in Indian Men with Differing Nutritional Status', *Clinical Science*, 81, pp. 419-425.

Sukhatma, P.V., and Margen, S. (1982): 'Autoregulatory Homeostatic Nature of Energy Balance', *American Journal of Clinical Nutrition*, 35, pp. 355-365.

Walker, S.P., Powell, C.A., and Grantham-McGregor, S. (1998): 'Early Childhood Supplementation and Cognitive Development During and After Intervention', in *Nutrition, Health and Child Development: Research Advances and Policy Recommendations* (Washington D.C., Pan American Health Organization), pp. 69-81.

Waterlow, J.C. (1984): 'Kwashiorkor Revisited: the Pathogenesis of Oedema and its Significance', *Transactions of the Royal Society of Tropical Medicine and Hygiene*, 78, pp. 436-441.

Waterlow, J.C. (ed.) (1988): 'Linear Growth Retardation in Less Developed Countries', in *Nestlé Nutrition Workshop Series no. 14* (Vevey, Nestlé Nutrition/New York, Raven Press).

Waterlow, J.C. (1988): 'Observations on the Natural History of Stunting', in *Linear Growth Retardation in Less Developed Countries*, eds. J.C. Waterlow and B. Schürch (Vevey, Nestlé Nutrition/New York, Raven Press), pp. 1-16.

Waterlow, J.C. (1992): *Protein-Energy Malnutrition* (Sevenoaks, Edward Arnold), p. 27.

Waterlow, J.C., and Schürch, B. (eds.) (1994): 'Causes and Mechanisms of Linear Growth Retardation', *European Journal of Clinical Nutrition*, Suppl. 1, pp. S1-S212.

Williams, C.D. (1935): 'Kwashiorkor: a Nutritional Disease of Children associated with a Maize Diet', *Lancet*, 2, pp. 1151-1152.

Young, V.R., Bier, D.M., and Pellett, P.L. (1989): 'A Theoretical Basis for Increasing Current Estimates of the Amino Acid Requirements in Adult Men, with Experimental Support', *American Journal of Clinical Nutrition*, 50, pp. 80-92.

MICRONUTRIENT DEFICIENCIES AND INTERVENTION

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INTRODUCTIONS

Malnutrition is a worldwide problem, affecting populations, especially in developing countries. Micronutrient malnutrition only gained attention less than ten years ago because its occurrence and consequences are not as visible as other diseases or as protein-energy malnutrition. Micronutrient deficiency is thus referred to as '*hidden hunger*'. Three major micronutrient deficiencies of global public health importance are: iron deficiency anemia (IDA), vitamin A deficiency (VAD) and iodine deficiency disorders (IDD) (WSC, 1990; ICN, 1992). The importance of malnutrition lies in several functional consequences that affect quality of life.

CONSEQUENCES OF MICRONUTRIENT MALNUTRITION

Deficiencies of these three nutrients affect human performance: in physical capacity and cognition; in relation to reproductive performance (pregnancy outcome and maternal mortality); in terms of permanent physical/mental damage; and in the field of child growth and development, and morbidity and mortality in childhood. Table 1 presents the health and functional consequences of iron, vitamin A and iodine deficiencies. Progression of deficiencies may range from early impairment, which are generally defined as the subclinical stage, to severe stages when overt clinical manifestations are apparent. Much work has been done to elucidate and establish the relationships between various stages of deficiency and its consequences.

Iron deficiency is now known to have deleterious effects throughout the life cycle. Iron deficiency with or without anemia was found to result in poor

Table 1. *Health and functional consequences of IDA, VAD and IDD.*

IDA	VAD	IDD
Human performance • ↓ physical capacity • ↓ cognitive and learning ability • ↓ immunity	Human performance • night blindness • keratomalacia • blindness • ↓ immunity	Human performance • ↓ cognitive and learning ability • permanent mental damage
Reproductive performance • poor pregnancy outcome • ↑ risk of maternal mortality	Reproductive performance • ↑ risk of maternal mortality	Reproductive performance • cretinism
• ↓ child growth and development	• ↓ child growth and development • ↑ childhood morbidity and mortality	• ↓ child growth and development

pregnancy outcome, ranging from low birthweight and prematurity (Scholl, *et al.*, 1992; Scholl and Hediger, 1994). Severe anemia was reported to be the cause of at least one-third of maternal mortality in poor developing countries (Bothwell and Charlton, 1981). Iron deficiency anemia occurring during infancy may have irreversible effects on cognitive potential as well as on the learning capacity of older children (Draper, 1997; Nokes *et al.*, 1998).

Iron deficiency can affect physical performance, work capacity and endurance among working adults (Viteri and Torun, 1974; Spurr, *et al.*, 1983; Basta, *et al.*, 1979; Edgerton, *et al.*, 1981; Li, 1993; Zhu and Haas, 1997). The relationship between iron deficiency and some immune functions, specifically cell-mediated immunity and the ability of neutrophils to kill bacteria, have also been demonstrated (Dallman, 1987).

Vitamin A is known for its role in vision, cellular differentiation and growth. Severe vitamin A deficiency leads to observable symptoms of ocular damage or xerophthalmia. The clinical signs begin with the early manifestation of night blindness, followed by dryness of the conjunctiva and severe corneal lesion to ulceration (keratomalacia), and eventually involve blindness (Sommer, 1982). Severe xerophthalmia has traditionally been associated with extraordinary mortality, particularly in children with severe protein-energy malnutrition (PEM) and measles. While clinical vitamin A deficiency poses a major threat to a child's health, children without ocular signs or subclinical vitamin A deficiency face significant functional consequences as well. These include growth retardation, impaired immunity, and increase the incidence and/or severity of infection and the risk of childhood mortality (Sommer and West, 1996). In addition, recent evidence from Nepal has indicated that vitamin A deficiency is associated with an increased risk of maternal mortality and that vitamin A supplementation helps to reduce mortality among Nepalese mothers (IVACG, 1997).

Depending on the severity, onset and duration of iodine *deficiency*, clinical manifestation can be observed during gestation and infancy. These include fetal mortality, perinatal mortality, abnormalities in brain and neurological development, and enlargement of the thyroid, or goitre (Hetzel, 1987). IDD was reported to be the single most preventable cause of mental deficiency and these adverse effects are maximal and irreversible if severe IDD occurs during pregnancy and a few years, and especially the first few months, after birth. Cretinism, the most severe form of IDD in infants, mental retardation and subnormal intelligence and psychomotor defects in normal-looking children, are the array of health and functional consequences in young children. A meta-analysis on iodine and intelligence revealed that children living in iodine-deficient area were, on average, 13.5 IQ below those living in the sufficient areas (Vermiglio *et al.*, 1990).

From this evidence it is clear that micronutrient deficiency is not always visible, or only when it reaches the severest stage can the clinical manifestation or permanent functional damages be recognized. What is also important is that even at the subclinical levels in all three micronutrient deficiencies significant detrimental effects on human ability and quality of life can occur. Women during the reproductive period, specifically, pregnant women and infants, are among the most vulnerable groups during the life cycle. Addressing micronutrient malnutrition used to be confined to the clinical and health sector. However, with its known consequences for quality of life, the risks of severe deficiencies, and permanent damage or death, concerted efforts are needed beyond the health sector alone. Agricultural, food and nutritional sciences can make significant contributions to addressing these problems, as will be described.

Requirements for Iron, Vitamin A and Iodine

The requirements of these micronutrients are very small compared to those of the macronutrients. However, although the body needs very small amounts of these micronutrients, deficiencies of these nutrients are common due to their inadequacy in diets to meet the demand, the increased requirement associated with physiological and pathological conditions, or the poor utilization of such nutrients. Nutrient requirements and recommendations for intakes usually provide figures of the safe range for most nutrients, i.e. not too low to meet the demand, or too high to cause toxicity. It is appreciated now that the higher intakes do not necessarily lead to nutritional benefiets. Moreover, the interactions among nutrients, particularly micronutrients, can result in the imbalance of the system, i.e. correcting one problem may create another simultaneously. Generally, recommended dietary intakes of any nutrient (except energy) to cover the needs of 97.5% of population (or the values of mean + 2SD) ensure that most people will be at a very low risk of having inadequacy. Therefore, periodically the recommended intakes of nutrients have been revised as more new knowledge becomes available.

For iron, the body has a tight regulation of the absorption triggered by the level of iron in the stores. This store, however, is also limited, as it may be the natural mechanism to prevent adverse effects. Vitamin A is slightly different in that its storage is larger than that of iron. Nevertheless, an accumulation of vitamin A up to a toxic level is possible. Iodine is present in the body to adequately supply the thyroid gland for the synthesis of thyroxin and other substances used in the metabolic regulation. Though the toxic level of iodine is believed to be very high (several times above the recommended level), recent evidence has shown that adults (often females) in a severely iodine-deficient population who received iodine within the acceptable range (100-200 mg/d) had an increased risk of developing thyrotoxicosis (WHO/UNICEF/ICCIDD, 1996).

Efforts have been made to define the levels of recommended dietary allowances especially appropriate for people living in developing countries. Due to differences in ethnicity, body size, living conditions and lifestyle, requirements among populations may differ significantly. Data on requirements in developing countries are, however, limited. UN agencies, specifically FAO and WHO, have consolidated these recommendations, which need periodical revision to suit changing problems, lifestyles and new knowledge on human requirements, both at individual and population levels. The Recommended Dietary Allowance (RDA) established by the National Academy of Sciences, National Research Council, U.S.A., has been adopted not only for the U.S. population, but by many developing countries. However, increasing knowledge on nutrient bioavailability raises questions about some of these recommendations, in addition to the fact that habitual diets differ from those of the U.S. population. Tables 2 to 4 present requirements or recommended intakes of iron, vitamin A and iodine for various age/sex groups.

The amount of recommended iron intakes from diets varies according to the bioavailability of iron (forms and amounts) in a given dietary pattern. Therefore, it is more appropriate to provide data on the amount of absorbed iron that is required (table 2). Thus recommended iron intakes may differ for a given country or population.

Table 2. *Iron requirements to cover 97.5% of the population in terms of absorbed iron by age and sex.*

Age/sex	Absorbed iron	
	µg/kg/d	mg/d
4-12 months	120	0.96
13-24 months	56	0.61
2-5 years	44	0.70
6-11 years	40	1.17
12-16 years (girls)	40	2.02
12-16 years (boys)	34	1.82
Adult males	18	1.14
Menstruating women	43	2.38
Pregnant women	*	*
Lactating women	24	1.31
Post-menopausal women	18	0.96

* No recommendation was made due to wide variation.
Source: De Maeyer, WHO, 1989.

Iron requirements in young children were around 1 mg/d or less, up to the period of rapid growth spurt when the requirements of boys and girls begin to rise and to increase over those of young childhood by almost or more than double, respectively. From then onwards, the menarche of females puts them on higher requirements throughout the menstruating period. Pregnancy adds more stress to iron needs, double to triple that of the requirements of adolescent girls. WHO did not recommend the level of iron requirement during pregnancy, as this may vary from population to population. It was estimated that this may range between 4-6 mg. of absorbed iron/d (Bothwell and Charlton, 1981). For most age groups, except pregnancy, diet manipulations have a good change to meet the needs of all groups. The requirement during pregnancy however, is so high that iron in medicinal form is a necessity.

Unlike iron, for both vitamin A and iodine there do not seem to be sex difference in requirements, except for vitamin A during the pubertal period (15-18yrs.) (tables 3 and 4). The increased needs are apparently associated with growth. During pregnancy the requirement of vitamin A remains the

Table 3. *Recommended dietary intakes of vitamin A.*

Age (yr.)/sex group	vitamin A, µg RE/d
0-1	350
1-6	400
6-10	400
10-12	500
12-15	600
Males, 15-18	600
Females, 15-18	500
Pregnancy	600
Lactation	850

Source: FAO/WHO, 1988.

Table 4. *Recommended dietary intakes of iodine.*

Age group, yr.	µg/d
0-1	50
2-6	90
7-12	120
>12	150
Pregnancy	200
Lactation	250

Source: WHO/UNICEF/ICCIDD, 1996.

same as that for adults (600 µg RE/d) and only increases during lactation (850 µg RE/d).

Iodine requirements, on the other hand, increase both during pregnancy and lactation (200 µg/d) from the levels recommended for adolescents and adults (150 µg/d). Nonetheless, requirements of vitamin A and iodine of most age groups can be achieved through a dietary or food-based strategy. Only among high risk groups in endemic areas is it likely that micronutrient supplementation will be necessary to prevent serious damage within the population.

CURRENT SITUATION ON MICRONUTRIENT MALNUTRITION

Tables 5-7 present the most recent information on the global magnitudes of IDA, VAD and IDD (ACC/SCN, 1997; IVACG 1997). In terms of the number of people affected, anemia, presumably due largely to iron deficiency, ranks the first: over a billion people were estimated to have the problem. On the other hand, IDA is the least visible, since only overt clinical signs can be recognized. Its eradication is also rather complex as several strategies need to be appropriately integrated. Concrete goals and major efforts have been made by international movements during the 1990s in relation to VAD and IDD, with the aim of eliminating clinical manifestations of both problems by the end of the year 2000 (WSC, 1990; ICN, 1992). This has resulted in a substantial reduction of the prevalence of VAD and IDD. Many countries, such as Indonesia and Vietnam, have reported a drastic reduction in clinical vitamin deficiency (WHO/UNICEF, MDIS, # 2, 1995). Details on each of the problems must be elaborated.

The magnitude of IDA among women is obviously the highest among all age groups, particularly during pregnancy. Southeast Asia (including the South Asian continent) had the highest prevalence (almost 80%) and number of people affected (over 22 million). Over half of school-aged children (5-14 years old) worldwide also had IDA and numbered 526 million. More than forty per cent of women during the reproductive years (15-59) were also affected. Underfive children are much less affected in terms of number. However, its important consequences on cognitive development, which may be irreversible, deserves high attention in order to achieve prevention.

The problem of VAD has received much attention due to its obvious permanent damage to the eyes, i.e. blindness. The reduction of the clinical prevalence by almost half during 1985 and 1995, meant that about 0.6% of children were affected globally. South Asia still ranks the highest in clinical prevalence with 1.58% compared to below 0.6% in most other regions of the world. Despite the impressive progress several countries have made, subclinical VAD continues to be a challenge, particularly in South Asia and most parts of Africa (except the north), where the prevalence of subclinical VAD remains around 20%.

Table 7 compares the trend of the percentage of the population at risk in relation to IDD between 1994 and 1997. The reduction of the population at risk by a half was achieved within three years. This magnitude of reduction is significant since the non-clinical form of IDD has deleterious effects on cognitive capacity (estimated to be 10-15% below normalcy) (Stanbury, 1993; Bleitchrodt and Born, 1993). Though the relationship has not been established, the remarkable achievement worldwide in terms of

Table 5. *Prevalence of IDA in children and reproductive-age women.*

Region	Children				Women			
	0-5		5-14		pregnant		15-59 yrs.	
	%	mill.	%	mill.	%	mill.	%	mill.
Africa	33.1	35.5	52.0	85.2	46.9	9.6	37.9	57.6
Non-industrialized America	22.9	13.0	36.9	39.5	39.0	3.8	31.0	44.9
Southeast Asia	52.7	93.8	63.9	207.8	79.6	22.2	60.0	218.6
Eastern Mediterranean	38.3	28.1	30.8	37.9	63.9	8.8	51.1	60.6
Non-industrialized West Pacific	14.7	19.7	56.9	156	38.5	9.4	33.8	152.9
Total	34	190	53	526	56	54	43	535

Source: WHO (in preparation) (Untitled. Micronutrient deficiency information system. Working paper No. 3, Who, Geneva. (cited after ACC/SCN, 1997.

Table 6. *Prevalence of VAD (Clinical) in developing countries by regions (1995).*

Region	Clinical prevalence		Subclinical prevalence	
	% prevalence	# (million)	% prevalence	# (million)
South Asia	0.95	1.58	19.2	32.3
East Asia/Pacific	0.25	0.40	9.1	14.8
Latin Amer./Caribbean	0.24	0.12	9.0	4.7
East/South Africa	1.06	0.53	20.0	10.0
West/Central Africa	0.87	0.45	18.1	9.4
Middle East/N. Africa	0.27	0.12	9.8	4.2
Total	0.63	3.30	14.6	75.4

Source: Sethuraman, *et al.*, 1997.

universal salt iodization may have accounted for the decline of clinical IDD. Continued efforts are still needed to monitor the quality of iodization of salt to ensure its lasting effects. Moreover, the challenge is to reach out to people who have less access to iodized salt.

Table 7. *% Population at risk of IDD between 1994 and 1997.*

Region	% Population at risk	
	1994	1997
Africa	32.8	23.4
America	23.1	6.6
Eastern Mediterranean	42.6	30.3
Europe	16.7	10.7
Southeast Asia	35.9	14.4
Western Pacific	27.2	9.8
Total	28.9	13.7

Source: WHO/UNICEF/ICCIDD, 1994 and WHO, 1997 (World Health Report, WHO, Geneva).

RISK FACTORS

1. MICRONUTRIENT AVAILABILITY FROM DIETS

1.1. *Food sources and micronutrients in diets*

Iron is the trace element that is not widespread in many varieties of foods. There are two forms of iron in foods: heme and non-heme iron. They differ in terms of absorbability. While heme iron is readily absorbable, the absorption of non-heme iron depends on the other constituents of the diet (to be elaborated in the next section). Heme iron is present only in animal sources, especially red meat and organ meat. Poultry and fish contain much less iron than beef. On average, 40% of iron in animal sources is heme iron and the rest is non-heme iron (Monsen *et al.*, 1978). Staple cereals (such as wheat, rice, corn) and legumes (soy beans, in particular) contain considerable amounts of non-heme iron, but the co-presence of the iron absorption inhibitor, phytate, prevents them from providing significant amounts of iron within the diet. Iron in eggs and milk, which are animal products, are not as available as in meat. Phosvidin in eggs, and calcium in milk, have some inhibiting effects on absorption. Very few kinds of vegetables and fruit contain substantial levels of iron. In addition to these factors, the cost of foods of animal origin and some plant sources may make them prohibitive for some poor sectors of the population.

Unlike iron, vitamin A can be found in a wide range of animal and plant sources. Animal foods such as liver, egg, or dairy products contain preformed vitamin A or retinol. Dark green leafy vegetables as well as yellow/orange colored fruits and vegetables contain provitamin A carotenoids, among which, β-carotene shows the highest biological activity. On the average, other provitamin A carotenoids (such as, alpha- and gamma- carotene and cryptowanthin) in foods possess approximately 50% of β-carotene activity. Not all provitamin A carotenoids are converted to vitamin A. Carotenoids in foods are less bioavailable than preformed vitamin A. To express the unit of vitamin A activity in foods, the retinol equivalent (RE) was created. One μg RE is equal to 1 μg of all-trans retinol to 6 μg of all-trans β-carotene, or to 12 μg of other provitamin A carotenoids (Olson, 1994). Beside vitamin A activity, vegetables and fruits are good sources of antioxidants and dietary fiber which have many health benefits, including disease prevention.

Iodine is present in even more limited food sources. Iodine is present mainly in sea foods. As can be observed, IDD is not endemic among people living near the sea or who have regular access to sea foods. Sea salt does not contain iodine at the level that can satisfy daily needs for iodine; indeed, the level of iodine in non-iodized sea salt was found to be quite low. Endemic areas of goitre tend to be those which are poor and distant from these food sources.

1.2. *Quality of diets – quantity of nutrients and their bioavailability*

Micronutrients in food are not necessarily readily available to the body for utilization. Therefore, knowing only the content of a given micronutrient in the diet is not sufficient to predict how much the body can actually make use the nutrients. The 'bioavailability' of micronutrients from foods, natural or fortified, has been a major issue in micronutrient nutrition. Nutrient interaction with other nutrients and non-nutrients leads to reduction in the availability of particular nutrients for absorption and utilization in the body.

The absorption of non-heme iron depends on the co-existence of an iron absorption enhancer and inhibitor. Therefore, while absorption of heme iron, which is readily absorbable and averaged 23%, that of non-heme iron may range 2-15%. Table 8 lists examples of foods which contain iron absorption enhancers and inhibitors.

Vitamin C was shown to be the strongest enhacer and is present in a wide varieties of fruits and vegetables. Not all sour-taste fruits and vegetables are high in vitamin C because there are other organic acids in fruits, such as tartaric acid in tamarind, which also gives a sour taste. Meat, in addition to its heme iron content, was found to be a good enhancer of

Table 8. *Iron absorption enhancers and inhibitors and examples of foods containing these compounds.*

Enhancers/inhibitors	Examples of foods
Enhancers:	
Ascorbic acid (vitamin C)	guava, orange, lime, kale
Organic acid e.g. malic, tartaric, succinic acid	fruits and vegetables
amino acids/peptides/meat protein	meat, fish
Inhibitors:	
phytate	cereal grains, vegetables
tannin	tea, coffee
calcium, phosphorous	milk, egg yolk

Source: Gillespie, 1998.

absorption of other non-heme iron in diets. The major inhibitors found in food are those of poly-phosphate containing compounds, phytate and tannin. Phytate is mostly found in cereal grains, legumes and several kinds of vegetables, and tannin in tea, coffee and some vegetables.

For a rough approximation, Monsen *et al.* (1978) proposed simplified rules to classify diets by iron bioavaiability. Diets containing less than 30 grams of meat, fish, poultry or less than 25 mg. vitamin C are low iron bioavailability diets, and absorption is only 3-4%. The intermediate iron bioavailability diet, involving an absorption of 7-10%, contains 30-90 grams of meat, fish, poultry or 25-75 mg. of vitamin C. Diets containing more than 90 grams of meat, fish, poultry or more than 75 mg. of vitamin C have high iron bioavailability, where iron absorption can be as high as 15-20%. The presence of inhibitors in these diets reduces the percent absorption beneath the expected level (Bothwell and Charlton, 1981).

Similarly, absorption of provitamin A carotenoids depends on dietary fat for efficient lipid micelle formation (Erdman *et al.*, 1993). A study from India indicates that about 10 gm of fat should be added to enhance absorption of dietary β-carotene (Reddy and Vijayaraghavan, 1995). Another study from Thailand reports that dietary fat at 20% of total energy intake showed beneficial effects of β-carotene absorption from green leafy vegetables (Tontisirin *et al.*, 1995).

Goitrogens were found in some vegetables, such as cabbage, and can interfere with iodine absorption from food. However, the levels of goitrogens that can exert such an effect has to be quite high (beyond the level generally consumed). Unless the consumption of these food is extraordinary high, there is no epidemiological evidence that goitrogen contributes significantly to the occurrence of IDD.

1.3. *Effects of food preparation, cooking and food processing*

Vitamin and mineral contents can be affected by food preparation, cooking and processing methods used in the home and the food industry. Cutting, washing, prolonged and high heat can lower and destroy carotenes and vitamin A in foods (Reddy *et al.*, in: *Empowering VA Rich Food*, 1995). For example, 10% of β-carotene is lost when cooking the same vegetable in a pot without a lid. As much as half of β-carotene in pumpkin is lost during cooking. Prolonged heating causes losses of 50-90% of β-carotene in carrot and pumpkin. Minerals are more resistant to cooking loss. However, its absorption enhancer, like vitamin C in the case of iron, can easily be destroyed by heat. There is not much information on loss of iodine in salt as a result of cooking. However, in a humid climate, iodine that is absorbed by the salt crystal during the iodization of salt may be leached out due to use of packaging material whereby the solution can seep through during prolonged storage.

2. SEASONALITY OF FOOD AVAILABILITY

Availability of foods may vary according to the seasons, particularly in rural areas. Vegetables and fruits containing vitamin A precursors, i.e., the carotenoids, are good examples of this. The incidence of xerophthalmia increases during the period that these foods are limited, during hot, dry seasons as well as during drought (Sommer and West, 1996).

3. AGE, SEX, PHYSIOLOGICAL STATES AND REQUIREMENTS

As previously shown in the requirement section, demographic characteristics, namely age, sex, and physiological conditions, determine the level of the nutrients required by the body. During growth, requirements of practically all nutrients increase to keep up with the rapid growth. Pregnancy is another period when some nutrient requirements, specifically iron, are so high that dietary sources may not be adequate to fulfill needs. For most age/sex groups, a food-based approach (fortification and dietary diversification), if appropriately optimized, can provide the daily level of requirement. Medicinal iron supplementation is needed during pregnancy because the requirement is too high to be met by usual diets, even in populations where animal sources are substantial in habitual diets.

4. Pathological States: Parasitism and Common Infection

Parasitic infestation is common in tropical zones. Hookworm, malaria, ascaris and trichuris are common parasitic infections which cause chronic blood loss, thus increasing the need for iron. Common infections such as diarrhoea, respiratory tract infections and measles, all increase the requirement for several nutrients, particularly vitamin A.

5. Protein-energy Status

VAD was found to be highly associated with severe and moderate PEM, since the transport and storage of nutrients, such as iron and vitamin A, require protein for their proper functioning. Moreover, PEM may reflect the inadequacy of overall food intake, especially among young children.

Intervention Strategies for Micronutrient Deficiencies

1. Increasing Food Availability and Nutrient Density

1.1. *Food sources and Food supplies*

Varieties of conventional sources provide a wide range of choices for micronutrient-rich foods. However, the availability of these foods may be limited by accessibility and affordability. Rural people in developing countries tend to live on plant sources, i.e., cereal grains and legumes, as the main part of their diets. Unlike protein and energy sources which may be made available from grains and several other sources, micronutrients are confined to more limited food items, with the exception of vitamin A and its precursors.

Increasing food sources may be done in one of two ways: by introducing new foods and identifying foods which have the nutritive values of interest but are not commonly consumed by the population in the endemic or high risk areas, or by introducing new food sources, such as the introduction of aqua-farming to increase animal sources; dairy farming to non-milk drinking population; or new plant varieties which are not indigenous to the area. New foods may need to be well integrated into the existing cropping pattern. The mobilization of people's participation is usually a crucial element to achieve success. Indigenous knowledge and local wisdom should be identified as they can be very useful if properly generated given that people may have lived in the area for generations. Improving breeds may be needed by plant breeding or gene modification to improve yields, pest resistance, and climatic and other forms of environmental adaptability.

Some varieties of indigenous food sources may be given low value and not used in habitual diets. Several examples of indigenous foods were reported to be provitamin-A carotene rich sources in rural areas in Nepal, India, Iondonesia and Thailand (FAO/INMU/SEAR-WHO research-cum-action, 1995). The promotion of their values and formulating recipes which make such foods more attractive and acceptable will be needed to promote both production and consumption.

An interesting approach was used in the study of pro-vitamin A rich foods in several countries in Asia which listed what is available at what time of year. The food sources can be recommended on the model of a food production calendar (FAO/INMU/WHO SEAR research-cum-action network, 1995). Some non-traditional fruits and vegetables were also identified and found to contain substantial levels of carotenes. Table 9 lists some fruits and vegetables identified in different countries. Moreover, the vitamin A content in the same fruits or vegetables was found to vary by season. Some examples of this are amaranthus, cassava leaves and sauropus leaves reported from Indonesia. Thus, identifying alternative food sources for different seasons and the use of food technology to make micronutrient rich food available year round is a productive policy.

Table 9. *Calendar of fruits and vegetables rich in provitamin A carotenoids in north-east Thailand.*

Year round	Ivy gourd, pumpkin, swamp cabbage, kale, Chinese green cabbage, amatanth	
Seasonal summer	*Rainy*	*Winter*
Sesbania leaves	Pumpkin, young leaves	Garlic leaves
Lead tree leaves	Chinese cabbage	Green onion leaves
Pak sein	Indian Penny Wort	Sweet potato, yellow
Ripe mango	Ripe papaya	Ripe papaya

Source: FAO/INMU/WHO SEAR research-cum-action network, 1995.

1.2. *Optimizing breeding strategy*

Agricultural technology may be utilised to increase supplies of food through better food production (to increase yield and nutrient density), making food available in time of scarcity, or increasing varieties/choices through breeding and genetic engineering. In the past, agricultural technology has been successfully developed to produce high yield varieties of cereal grains, such as rice. Most staple crops, with the exception of maize and sweet potatoes, are not good sources of vitamin A. However, the focus on grains as a cheap source of energy and protein, which, it was thought, would reach the poor, had an unintended consequence for the diversity of cropping systems. Farmers preferred to grow high yield, more profitable, grains to low calorie foods which are high in protein and micronutrient (Bouis, in press). High carotene horticulture crops include carrots, melons, papaya, mangos, tomatoes, spinach, squash, oranges, and tangerines (Simon, in press).

Welch has suggested that an optimal breeding strategy for minerals can be used to increase mineral density, or decrease the density of antinutrient substances and/or increase the density of promoter substances (Welch, 1996). Micronutrient density has been found to be neutral or positively correlated with yields (Graham *et al.*, 1997). A study on varieties of rice revealed that there is a wide variation in the level of both iron and zinc. Iron contents of several varieties of aromatic rice were consistently found to be 30-40% higher than in non-aromatic rice, though this may depend on soil fertility. Only some high yield breeders' lines were high in micronutrient density, but most were around the group average. Rice genotypes, which contain around twice the mean iron density, were quite rare (1% of the 939 lines studies). Moreover, the stability and adaptability of plants over a range of climate and environment are also important factors. Ultimately, high yield, high density and bioavailability are the goal. Thus, the challenge for breeders to develop the variety that is both high yield and high density continues to be very important.

A further question is: even if a high micronutrient density variety can be developed what does this involve for the bioavailability of the new varieties? In cereal grains and beans the levels of important antinutrients such as phytate (often > 10 milligram/g dry weight) are exceedingly higher than the levels of micronutrients such as iron (usually in the range of 20-100 microgram/g dry weight). In some animal models there is evidence that increased iron concentration in staples significantly improves the bioavailable iron. It is known that bioavailability differs between human and animal models (rats or mice), but the cost of such human studies can be prohibi-

Table 10. *Agricultural technology and post-hatvest management to improve the micronutrient contents of foods.*

Technology	Iron	Vitamin A
agricultural technology	Genetic engineering of plants: rice, pea	Genetic engineering super carrot
post harvest management	–	ripening: ↑ carotenoids in many fruits high storage temp: ↑ losses

Source: Micronutrient and Agriculture, 1996.

tive. The screening of large number of varieties by animal models can be a first screening step to reduce the number of varieties for further tests of bioavailability. More work in this area continues be needed.

Post-harvest management also contributes to the retention or loss of micronutrients. Much information has been provided on performed vitamin A. In many carotenogenic fruits, carotenoid content increased during ripening or as maturity progressed. This happened with several varieties of mango, pepper, and persimmon (Rodriguez-Amaya, 1997). Ripening is accompanied by enhanced carotenoid biosynthesis and carotenogenesis continues if the fruits or vegetables remain intact. Fruits which color at the ripe stage owe this to anthocyanins; these which retain a green color have their carotenoid levels reduced during ripening. The yellow color of banana is caused by the unmasking of carotenoids due to chlorophyll degradation. Total carotenoid loss in some vegetables, especially leaves, may take place during storage. High storage temperature can also aggravate carotenoid losses in kale, collard and turnip greens.

1.3. *Biodiversity and food availability*

As pointed out by Welch *et al.* (1997), the focus on grains to meet energy demands for the poor at a low cost had an unintended consequence for food and crop diversity. The diversity of traditional cropping sytems was reduced as a result of farmers' adoption of a simpler rotation of high yield and profitable grains and the abandonnent of low calorie foods which may be high in both protein and micronutrient. The maintenance of biodiversity is important for health since a varied diet is essential to maintain health and may also provide a rich source of medicinal materials which have a therapeutic quality. A diverse range of food sources increases the opportunity to safeguard climatic and infestations disasters by providing substitutes. Finally, an intact ecosystem of indigenous plants and animals may act as a buffer to the spread of pathogens and toxins (Wahlqvist, 1998). Therefore, preserving and promoting biodiversity of both plants and animals, whether for food or the benefit of the ecological system, will have important implications for human food sources and the supply of mixes of nutrients to maintain body balance. The degradation of the ecosystem has a significant impact on biodiversity. Exploitation of some indigenous plants and animals for commercial purposes has occurred and should be prevented. Current knowledge on biodiversity may have been more limited than realized. Much more attention and concerted efforts are urgently needed on the part of both academics and several professional areas, policy makers and planners to maintain the biodiversity of both plants and animals for nutritional and health benefits to be gained for the world's population.

2. Improving Diet Quality and Bioavailability Through Fortification

The fortification, enrichment and restoration of nutrients in and to food has been one food-based approach recommended for the tackling of micronutrient malnutrition. Developed countries have successfully eradicated some micronutrient deficiencies, such as IDD, through fortification (Ralte, AL, 1996). One advantage is that fortified food can be produced with good quality control in well-equipped factories to ensure suitable levels of nutrients and to provide fortified food through the existing food distribution system. Food fortification in developing countries is also promising, as several countries have now developed various micronutrient fortified products such as vitamin A fortified margarine in the Philippines; instant noodles in Indonesia; triple fortification of iron, vitamin A and iodine in the seasoning sachets of instant noodle in Thailand; vitamin A fortification in sugar in Guatemala; and double fortified iodine and iron in salt in India (Micronutrient Initiative, MI, 1998). Table 11 lists some examples of foods fortified with iron and vitamin A which are now commercially available in some developing countries.

The fortification of foods can actually take two forms, namely, nutrient to food and food to food fortification. Nutrient fortification may be more familiar in most places and has been effected through large scale industry using high technology and a complex process of quality control. Moreover, in countries where the food distribution system is not well developed centrally produced food may not be accessible, and often not affordable by the majority of people. Therefore, nutrient fortification may be appropriate where these factors can adequately be provided, or where appropriate tech-

Table 11. *Selected food fortification with iron, vitamin A and iodine.*

Intervention	Iron	Vitamin A	Iodine *
Fortification:			
• nutrient fortification	salt, fish sauce, soy sauce, flour, breakfast cereals	butter, margarine, sugar, wheat flour, condiments	salt
• food-to-food fortification	hemoglobin	liver	–

Source: Micronutrient Initiative, 1998.

nology can be developed with a good quality control system to make possible the smaller scale production of fortified foods.

An important problem in food fortification is the identification of appropriate food as a vehicle for micronutrients. Salt is probably the most agreed solution recommended for iodization as it is used in practically all countries. Universal salt iodization has been strongly promoted by UN agencies involved with food and nutrition. The quality control of salt, however, is a significant matter, especially where there are large number of small salt producers. Simple-to-use test kits for iodine have been developed. However, most of the available test kits are qualitative or semi-quantitative. The titration method is still the best method to ensure the quality control of iodized salt. Difficulties in most countries lie in the need to set up a laboratory to conduct the test and to provide the result promptly for the producers so to ensure the quality of the iodized salt which has been produced.

To address this problem of quality control for small-scale salt iodization, a study has been conduced in secondary schools in Thailand (Chavasit *et al.*; Institute of Nutritional, Mahidol University (INMU), personal communication) in order to make use of existing science laboratory facilities. School teachers were trained in titration techniques and quality control systems, which include good laboratory practices, and they are periodically monitored by the use of reference material provided by a qualified laboratory. They can then train students during the regular science class or make it a science project. A system is now being set up to link the salt producers to these schools so that iodized salt samples can be sent on a routine basis and results assured in due course. This model is very promising as it has created awareness among local afficers involved in salt iodization, students, and teachers, about the needs of their communities (the salt producing community), and participation is impressive.

Food-to-food fortification is an alternative which can be made at more varied levels of production, from household to large scale industry. In this manner, the food distribution system may be less of an obstacle. Nevertheless, a good quality control mechanism needs to be established. The enrichment of crisps and cookies by adding liver or animal blood (such as chicken or bovine blood) was found to increase vitamin A and iron content of foods in a way which was readily acceptable to people (Uraiporn *et al.*, 1997; Chavasit *et al.*, INMU, personal communication). More work is needed to establish the feasibility of expanding these efforts at various levels and to assess costs. Participation of people at the household and community level will be one area that needs to be explored and evaluated for cost-effectiveness.

In addition to food fortification, water iodination has also been used in some countries such as Malaysia (Foo *et al.*, 1996) and Thailand (MOPH and UNICEF, Thailand, 1997). There is also incidental iodine addition to food due to processing. Examples of this are iodine in milk from the use of iodophors as disinfectants in the cleaning of equipment or fortifiers added in fodder; and iodate added as a conditioner in bread making (Burgi and Helbling, 1996).

3. IMPROVING DIET QUALITY AND BIOAVAILABILITY THROUGH OTHER FOOD TECHNOLOGY METHOD

Food science and technology can play a pivotal role in increasing the availability of nutritive foods through various food processing and preservation methods. These include germination, fermentation, solar drying and candying (table 12).

The germination of cereal grains has been found to reduce phytate content so that iron intrinsic in grains and from other source taken with these

Table 12. *Food processing and preservation of micronutrient-rich foods and the increase in the bioavailability of micronutrients.*

Technology	Iron	Vitamin A
germination	cereals	–
fermentation	soy products such as soy sauce, tempeh	pickles
solar drying	–	dried fruits
candying	–	candied fruits

Table 13. *Food preparation and cooking to preserve micronutrients.*

Food prep.	Iron	Vitamin A
addition of enhancers and/or reduction of inhibitors	*Add:* vitamin C, meat *Reduce:* use phytase to reduce phytate	*include* fat in diets (increase adsorption of vitamin A)
cooking method	*avoid* prolonged cooking (vitamin C destroyed)	*avoid* excessive cut and washing, prolonged cooking (heat & oxygen)

cereals can be more available for absorption. Fermentation, which is a common preservation technique used both in traditional practices and industry, has also been found to increase the availability of certain vitamins and minerals, such as vitamin A and iron (FAO/INMU/WHO SEAR research-cum-action network, 1995).

In addition to food processing and preservation methods, food preparation and cooking practices can help to increase, or cause significant losses of, micronutrients (table 13). This information should be recognized in order to retain the nutritive values of micronutrients in commonly eaten foods.

4. Diet Diversification

In addition to identifying nutrient rich foods, there is the policy of diversifying foods to include or increase food and therely help to increase the bioavailability of micronutrients of circumvent limitations by proper menu planning. Some examples of this are given in table 14.

For iron, potential enhancers and inhibitors present in foods must be

Table 14. *Dietary diversification and modification.*

Intervention	Iron	Vitamin A	Iodine *
Diet diversification and modification	↑ *absorption enhancers:* animal sources, vitamin C, organic acid ↓ *inhibitors:* phytate and tannin	↑ *vitamin A and B-carotene rich foods:* animal sources, orange and yellow fruits & vegetables *fat consumption*	*Include:* sea food *Avoid:* goitrogenic food

recognized. Animal sources not only provide heme, the more bioavailable form, but also help to enhance the absorption of non-heme iron. Heme iron is readily absorbable, but the absorption of non-heme iron depends on the co-presence of enhancers and inhibitors (Monsen *et al.*, 1978, 1981; Hallberg, 1992; INACG, 1981). Tea or coffee drunk with a continental breakfast was found to reduce iron absorption significantly, but the addition of orange juice (i.e. a high amount of ascorbic acid) can circumvent the reduction in iron absorption (INACG, 1981). Leaves of the lead tree, which is commonly consumed in Thai habitual diets, contain tannin, and the amount commonly eaten can reduce iron absorption by about sixfold (from 12% to 1.7%) (Tuntawiroon, 1991).

Vitamin A in animal sources appears to be especially present in certain foods, such as organ meat. Liver is a good example as only one lobe of chicken liver provides more vitamin A than that required in a day. Once it is consumed, the vitamin A can also be stored. Thus, plant sources may be consumed on a daily basis, whereas animal sources can be consumed less frequently, for example once or twice a week.

Food sources for iodine are rather limited, as iodine is high in sea foods and a few plant sources such as types of sea weed. The iodization of salt and other condiments, such as fish sauce and soy sauce, are potential candidates for fortification, which needs to be properly promoted on an expanded scale and used in the home preparation of food.

Given such knowledge, the choice of foods and menu planning can be properly done. Nutrition education will be crucial and must be planned as an integral part of dietary diversification efforts.

5. PUBLIC HEALTH MEASURES

Although a food-based strategy appears to be a sustainable intervention, in certain circumstances nutrient supplementation in medicinal forms may be necessary (table 15). Pregnancy is one of the most vulnerable periods for both mothers and the fetus, especially in endemic areas of micronutrient malnutrition, and the health consequences of this have been discussed above. Routine, daily iron supplementation is inevitable for pregnant women in most populations as iron needs during the last two trimesters are much higher than can be supplied from habitual diets, even in developed countries. In the case of vitamin A and iodine supplementation, these may be needed in high risk or endemic areas in order to prevent deficiencies. Uses of high dose supplementation are otherwise needed as a curative measure, when evident deficiencies are identified. Lower doses and less fre-

Table 15. *Public health measures for the prevention and control of micronutrient malnutrition.*

Intervention	Iron	Vitamin A	Iodine *
Public health: (suplementation) • prevention	• *weekly, low dose:* adolescent girls and young women • *daily, high dose:* pregnant women	• *low dose: pregnant and* lactating women • *high dose (4-6 mo. interval):* high risk groups and high risk areas	• high dose (200-480 mg given orally, yearly; or oil injection (240 mg. for children <1 year or 480 mg for other groups) every 4 years
• treatment	*daily, high dose:* clinical cases	*high dose:* clinical cases	surgery for large size goitre
Deworming	Hookworm, Ascaris	–	–

quent supplementation (for iron) or lower doses and more frequent (vitamin A) supplementation have been studied and suggested as preventive measures. Work is in progress on the feasibility of this strategy.

In addition, other public health measures, particularly deworming, are also commonly recommended in areas where parasitism is highly prevalent, and this is an important complementary strategy where iron deficiency is highly prevalent. Caution must be taken in the case of pregnant women, as deworming must not be done during the first trimester.

LINKING PHYSICAL AND BIOLOGICAL FACTORS AFFECTING MICRONUTRIENT NUTRITION TO FOOD PRODUCTION IN THE PREVENTION AND CONTROL OF MICRONUTRIENT DEFICIENCIES

To address the challenges in the prevention and control of micronutrient deficiencies, systematic planning and the use of current knowledge in food sciences and technology, agriculture, and nutrition will be necessary. Increasing food availability should not focus only on increasing yields of certain food crops, particularly if micronutrient malnutrition is the major issue. Food production will need to consider crop diversity, and the identification of nutritive, indigenous and non-conventional food sources along with increased yields. Agricultural technology is needed to develop micronutrient rich varieties (increased nutrient density) and promote its use by the population where micronutrient malnutrition is prevalent. Bioavailability of new foods or new products will also need to be studied together with new developments.

Food processing and preservation at both household/community and industry levels can be explored and promoted, and should include both conventional and non-conventional food sources in order to increase choices of foods, especially where seasonality may be an important factor in food availability. Nutrient and food fortification can be adopted as appropriate but this depends the very much on a country's capacity for food manufacturing as well as its distribution system. Knowledge on effects of food preparation can be applicable to both the household and commercial levels to preserve micronutrients in foods. Diet diversification in order to include both animal and vegetable sources is also rather important and should include a proper mix of animal and plant sources which will achieve a trade-off between nutritive quality and costs. This is quite important in the case of a poor population where resources are limited.

The appropriate mix of the strategies will also need to take into account the magnitude and severity of the problems, and the mapping of target populations and areas where problems need to be tackled. Some have suggested assessing situations and groupings in terms of levels of the severity of problems and with mixes of interventions (IOM, 1998). Given the nature of the problem, micronutrient malnutrition is not likely to occur singly. An intervention strategy will possibly need to address multiple nutrients.

A successful program does not only depend on having the technical information and technical know-how on each area of possible intervention. It is very much a question of the approach and the implementation process. Given the nature of nutritional problems, there is no magic bullet solution. It has to be addressed employing a multidisciplinary approach. The agricultural, food and nutritional sciences are important areas as they are directly related to providing food for good nutrition. To be able to implement the program effectively, there is a need to understand the community's way of life, cultural beliefs and patterns, and so on. An integration of the social sciences will be crucial to identifying socio-cultural and behavioral factors which will facilitate implementation and improve the program's efficiency, effectiveness, and sustainability. Nutrition education and communication has also received high priority as both a short and long term strategy for promoting proper behavior and behavioral change.

Lastly, the most challenging issue for a nutrition program is sustainability. If it is agreed that nutrition is a matter of everyone and everyday, no top down program can provide such a service. Important elements include people's participation, interactive monitoring schemes (i.e. with built-in feedback loops), process evaluation, and output and outcome indicators. Community participation is of particular importance in implementation and sustainability because people are the real actors in correcting the problem and continuing with prevention. Government officers or other personnel (e.g. NGOs or the private sector) only play supporting roles, such as providing technical consultancy, training, facilitating links and the mechanisms for resource allocation. Cost-effectiveness, though, is an important concern for policy makers, and planners should not alone decide on the policies of intervention. These relevant issues should all be addressed in the program's planning and implementation.

REFERENCES

ACC/SCN (1997): *Third Report on the World Nutrition Situation* (World Health Organization, Geneva, Switzerland).

Basta, S., Soekirman, Karyadi, D., and Scrimishaw, N.S. (1979): 'Iron Deficiency Anemia and the Productivity of Adult Males in Indonesia', *Am. J. Clin. Nutr.*, 32, pp. 916-925.

Bleitchrodt, N., and Born, M.P. (1993): 'A Meta-analysis of Research on Iodine and its Relationship to Cognitive Development', in J.B. Stanbury (ed.), *The Damaged Brain of Iodine Deficiency: Cognitive, Behavioral, Neuromotor, Educative Aspects*, pp. 195-200.

Bothwell, T.H., and Charlton, R.W. (1981): *Iron Deficiency in Women. International Nutritional Anemia Consultative Group (INACG)*, (Washington, D.C., U.S.A.).

Bouis (in press): 'Improving Dietary Diversity: Plant Breeding as Part of the Solution', in *Micronutrient and Agriculture. Plant Breeding Strategies for Improving Human Mineral and Vitamin Nutrition*, number 3.

Burgi, H., and Helbling, B. (1996): 'Methods of Iodine Supplementation. What is best Where?' in Nauman, J., Glinoer, D., Bravermasn, L.E., Hostalek, U. (eds.), *The Thyroid and Iodine* (Schattaur, New York), p. 59.

Dallman, P.R. (1987): 'Iron Deficiency and the Immune Response', *Am. J. Clin. Nutr.*, 44, pp. 329-334.

De Maeyer, E.M. (1989): *Preventing and Controlling Iron Deficiency Anaemia through Primary Health Care. A Guide for Health Administrators and Programme Managers* (World Health Organization, Geneva, Switzerland).

Draper, A. (1997): *Child Development and Iron Deficiency. The Oxford Brief* (OMNI/ILSI, Washington, D.C., U.S.A.).

Edgerton, V.R., Ohira, Y., Hettiarachi, J., Senewwiratne, B., Gardner, G.W., and Bernard, R.J. (1981): 'Elevation of Hemoglobin and Work Performance in Iron Deficient Subject', *J. Nutr. Sci.*, 27, pp. 77-86.

Erdman, J.W., Bierer, T.L., Gugger, E.T. (1993): 'Absorption and Transport of Carotenoids', *Ann. N.Y. Acad. Sci.*, 691, pp. 76-85.

Foo, L.C., Zainab, T., Goh, S.Y., Letchuman, G.R., Nafikudin, M., Doraisingam, P., and Bak Khalid (1996): 'Iodization of Village Water Supply in the Control of Endemic Iodine Deficiency in Rural Sarawak, Malaysia', *Biomed. Environ. Sci.*, 9(2-3), pp. 236-241.

FAO/INMU/WHO SEAR research-cum-action network (1995): *Empowering Vitamin A Foods. A Food-based Process for the Asia and Pacific Region* (FAO Regional Office for Asia and the Pacific, Institute of Nutrition, Mahidol University and WHO Southeast Asia research-cum-action network, Bangkok, Thailand).

FAO/WHO (1992): *International Conference on Nutrition, Nutrition and Dvelopment* (Rome, Italy).

FAO/WHO Expert Consultation (1988): *Requirements of Vitamin A, Iron, Folate and Vitamin B12* (Food and Nutrition Series, No. 23, FAO, Rome).

Graham, R.D., Senadhira, D., and Ortiz-Monasterio, I. (1997): 'A Strategy for Breeding Staple-Food Crops with High Micronutrient Density', *Soil Sci. Plant Nutr.*, 43, pp. 1153-1157.

Hallberg, L. (1981): 'Bioavailability of Iron from Different Meals. Nutrition in Health and Disease and International Development', *Symposia from the XII International Congress of Nutrition*, pp. 333-343.

Hetzel, B.S. (1987): 'An Overview of the Prevention and Control of Iodine Deficiency Disorders', in Hetzel, B.S., and Stanbury, J.B. (eds.), *The Prevention and Control of Iodine Deficiency Disorders* (Elsevier), p. 10.

IVACG (1997): 'Sustainable Control of Vitamin A Deficiency' (Report of the XVIII International Vitamin A Consultative Group meeting. Cairo, Egypt 22-26 September, 1997).

Institute of Medicine (IOM) (1998): *Prevention of micronutrient deficiencies: Tools for Policy Makers and Public Health Workers* (National Academy Press, Washington, D.C.).

Li, R. (1993): 'Functional Consequences of Iron Deficiency in Chinese Female Workers' (Thesis, Wageningen, Nederland).

Micronutrient Initiative (1998): 'Food Fortification to End Micronutrient Malnutrition: State-of-the-art' (Symposium report, Satellite conference of the XVth International Congress of Nutrition, Montreal, Canada, August, 2, 1998).

Ministry of Public Health (MOPH) and UNICEF Thailand (1997): *Tracking the Progress Towards the Sustainable Elimination of Iodine Deficiency Disorders in Thailand* (Thailand, September 1997).

Monsen, E.R., Hallberg, L., Layrisse, M., Hegsted, D.M., Cook, J.D., Mertz W., and Finch, C.A. (1978): 'Estimation of Available Dietary Iron', *Am. J. Clin. Nutr.*, 31, pp. 134-141.

Monsen, E.R., and Balintfy, J.L. (1982): 'Calculating Dietary Iron Bioavailability: Refinement and Computerization', *J. Am. Diet. Assoc.*, 80, pp. 307-311.

Nokes, C., van den Bosch, C., and Bundy, D.A.P. (1998): *The Effects of Iron Deficiency and Anemia on Mental and Motor Performance, Educational Achievement and Behavior in Children. An Annotated Bibliography* (INACG, Washington, D.C., U.S.A.).

Olson, J.A. (1994): 'Vitamin A, Retinoids and Carotenoids', in Shils, M.E., Olson, J.A., Shike, M. (eds.), *Modern Nutrition in Health and Disease*, Vol. 1, 8th edition, pp. 287-307.

Ralte, A.L. (1996): 'Progress in Overcoming Micronutrient Deficiencies: 1989-1994', in Messer, E., and Uvin, P. (eds.), *The Hunger Report: 1995* (Alan Shawn Feinstein).

Reddy, V., and Vijayaraghavan, K. (1995): *Carotene Rich Foods for Combating Vitamin A Deficiency* (National Institute of Nutrition, Huderabad, India).

Rodriguez-Amaya, D.B. (1997): 'Carotenoids and Food Preparation: the Retention of Provitamin A Carotenoids in Prepared, Processed and Stored Foods' (OMNI project), pp. 25-34.

Scholl, T.O., Hediger, M.L., Shearer, J.W., and Fischer, R.L. (1992): 'Anemia vs Iron Deficiency: Increased Risk of Preterm Delivery in a Prospective Study', *Am. J. Clin. Nutr.*, 55, pp. 985-988.

Scholl, T.O., and Hediger, M.L. (1994): 'Anemia and Iron Deficiency Anemia: Compilation of Data on Pregnancy Outcome', *Am. J. Clin. Nutr.*, 59 (supp.), pp. 492S-501S.

Sethuraman, K., Dalmiya, N., Mason, J., Lotfi, M., and Alnwick, D. (1997): 'Progress in Controlling Vitamin A Deficiency' (UNICEF/Micronutrient Initiative/Tulane University, U.S.).

Sommer, A. (1982): *Field Guide to the design and Control of Xerophthalmia*. Second ed. (World Health Organization, Geneva).

Sommer, A., and West, K.P. Jr. (1986): *Vitamin A Deficiency Health Survival and Vision* (Oxford University Press, New York).

Spurr, G.B., Reina, J.C., Danners, H.W., Barrac Nieto, M. (1983): 'Marginal Malnutrition in School-aged Colombian Boys: Functional Consequences in Maximum Exercise', *Am. J. Clin. Nutr.*, 37, pp. 834-847.

Thilly, C.H. (1981): 'Goitre et Cretinisme Endemiques; Role Etiologique de la Consommation de Maniac et Strategie d'Eradication', *Bull. Acad. Med. Bel.*, 136, pp. 389-412.

Tuntawiroon, M., Sritongkul, N., Brune, M., Rossander-Hulten, L., Pleehachinda, R., Suwanik, R., and Hallberg, L. (1991): 'Dose-dependent Inhibitory Effect of Phenolic Compounds in Foods on Nonheme Iron Absorption in Men', *Am. J. Clin. Nutr.*, 53, pp. 554-557.

World Hunger Program, Brown University (Gordon and Breach Publishers), Chapter 9.

Simon, P.W. (in press), 'Carotene-Enriched Carrots', in *Micronutrient and Agriculture. Plant Breeding Strategies for Improving Human Mineral and Vitamin Nutrition*, No. 3.

Stanbury, J.B. (1993): *The Damaged Brain of Iodine Deficiency: Cognitive, Behavioral, Neuromotor, Educative Aspects*, p. 335.

Tontisirin, K., Kamtrakul, R., Kuhathong, K., Chantraruksa, V., and Valaipatchara, U. (1995): *Effect of Dietary Fat and β-carotenefrom Green Leafy Vegetable Supplementation on Vitamin A Nutrition in Preschool* (The 7th Asian Congress of Nutrition, Beijing, China, October 7-11, 1995), abstract, p. 593.

Viteri, F.E., and Torun, B. (1974): 'Anemia and Physical Work Capacity', *Clin. Haemat*, 3, pp. 609-626.

Wahlqvist, M.L., and Specht, R.L. (1998): 'Food Variety and Biodiversity: Econutrition', *Asia-Pac. J. Clin. Nutr.*, 7(3/4), pp. 314-319.

Welch, R.M. (1996): 'The Optimal Breeding Strategy is to Increase the Density of Promoter Compounds and Micronutrient Minerals in Seeds', in *Micronutrients and Agriculture. Plant Breeding Strategies for Improving Human Mineral and Vitamin Nutrition*, No. 1, February 1996.

Welch, R., Comb, G., and Duxbury, J. (1997): 'Towards a Greener Revolution', in *Issues in Science and Technology* (Fall 1997), pp. 50-58.

WHO/UNICEF (1995): *Global Prevalence of Vitamin A Deficiency* (MDIS Working paper # 2).

WHO/UNICEF/ICCIDD (1994): *Indicators for Assessing Iodine Deficiency Disorders and their Control Through Salt Iodization* (WHO, Geneva, cited after ACC/SCN).

WHO/UNICEF/ICCIDD (1996): *Recommended Iodine Levels in Salt and Guidelines for Monitoring their Adequacy and Effectvieness.*

WHO (in preparation), *Micronutrient Deficiency Information System* (Working paper No. 3, WHO, Geneva, cited after ACC/SCN).

World Summit for Children (1990): *World Declaration on the Survival, Protection and Development of Children* (United Nations, New York, U.S.A. September 1990).

Xue-Yi, C., Xin-Min, J., Zxhi-Hong, D., *et al.* (1994): 'Timing of Vulnerability of the Brain to Iodine Deficiency in Endemic Cretinism', *N. Engl. J. Med.*, 331, pp. 1739-1744.

Zhu, Yi, and Haas, J.D. (1997): 'Iron Depletion without Anemia and Physical Performance in Young Women', *Am. J. Clin. Nutr.*, 66, pp. 334-341.

V.

REMEDIAL APPROACHES

DEVELOPING SUSTAINABLE AGRICULTURAL SYSTEMS FOR SMALL FARMERS IN LATIN AMERICA

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INTRODUCTION

Most agricultural scientists today recognize that traditional systems and indigenous knowledge will not yield panaceas for agricultural problems in the developing world (Altieri, 1995; Gliessman, 1998). This is not to say, however, that traditional ways of farming refined over many generations by intelligent land users cannot provide key insights into sustainably managing soils, water, crops, animals and pests (Thrupp, 1998). Many scientists wrongly believe that traditional systems do not produce more because hand tools and draft animals put a ceiling on productivity. Productivity may be low but the causes appear to be more social, rather than technical. When the subsistence farmer succeeds in providing food, there is no pressure to innovate or to enhance yields. As it will be demonstrated herein, however, agroecological field projects led by NGOs show that traditional crop and animal combinations can be optimized to increase productivity when the biological structuring of small farms is improved and labor and local resources are efficiently used.

For agroecologists committed to helping poor farmers raise the productivity and sustainability of their small holdings, a crucial task has been to understand the features of traditional agriculture, such as the ability to bear risk, biological folk taxonomies, the production efficiency of symbiotic crop mixtures, etc. Such research has provided important information on how to develop agricultural technologies best suited to the needs and circumstances of specific peasant groups, thus becoming a critical input for the application of agroecology in rural development programs.

Since the early 1980s more than 200 projects promoted by NGOs in Latin America have concentrated on promoting agroecological technologies which are sensitive to the complexity of peasant farming systems (Altieri and

Masera, 1993). This agroecological approach offers an alternative path to agricultural intensification by relying on local farming knowledge and techniques adjusted to different local conditions, management of diverse on-farm resources and inputs, and incorporation of contemporary scientific understanding of biological principles and resources in farming systems. Second, it offers the only practical way to actually restore agricultural lands that have been degraded by conventional agronomic practices. Third, it offers an environmentally sound and affordable way for smallholders to sustainably intensify production in marginal areas. Finally, it has the potential to reverse the anti-peasant biases inherent in strategies that emphasize purchased inputs and machinery, valuing instead the assets that small farmers already possess, including local knowledge and the low opportunity costs for labor that prevail in the regions where they live (Altieri *et al.*, 1998).

This paper contends that there is enough evidence available – despite the fact that researchers have paid little attention to alternative cropping systems – to suggest that agroecological technologies promise to contribute to food security on many levels. Critics of such alternative production systems point to lower crop yields than in high-input conventional systems. Yet all too often, it is precisely the emphasis on yield, a measure of the performance of a single crop, that blinds analysts to broader measures of sustainability and to the greater per unit area productivity and environmental services obtained in complex, integrated agroecological systems that feature many crop varieties together with animals and trees.

Assessments of various initiatives in Latin America show that agroecological technologies can bring significant environmental and economic benefits to farmers and communities (Altieri, 1995; Pretty, 1995; Thrupp, 1996). If such experiences were to be scaled up, multiplied, extrapolated, and supported in alternative policy scenarios, the gains in food security and environmental conservation would be substantial. This article summarizes some cases from Latin America that explore the potential of the agroecological approach to sustainably increase productivity of smallholder farming systems, while preserving the resource base and at the same time empowering local communities.

THE CONTRIBUTION OF TRADITIONAL AGRICULTURE TO FOOD PRODUCTION AND SUSTAINABILITY

Despite the increasing industrialization of agriculture, the great majority of the farmers in Latin America are peasants, or small producers, who still farm the valleys and slopes of rural landscapes with traditional and subsistence methods. In many areas of the region, traditional farmers have developed and/or inherited complex farming systems, adapted to local conditions, that have helped them to sustainably manage harsh environments and to meet their subsistence needs, without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science (Denevan, 1995).

The persistence of more than three million hectares under traditional agriculture in the form of raised fields, terraces, polycultures, agroforestry systems, etc., document a successful indigenous agricultural strategy and comprises a tribute to the "creativity" of peasants throughout Latin America. These microcosms of traditional agriculture offer promising models for other areas as they promote biodiversity, thrive without agrochemicals, and sustain year-round yields. An example are the chinampas in Mexico which according to Sanders (1957) in the mid 1950s exhibited maize yields of 3.5 to 6.3 tones per hectare. At the same time, these were the highest long-term yields achieved anywhere in Mexico. In comparison, average maize yields in the United States in 1955 were 2.6 tones per hectare, and did not pass the 4 tones per hectare mark until 1965. Sanders (1957) estimated that that each hectare of chinampa could produce enough food for 15 to 20 persons per year at modern subsistence levels. Recent research has indicated that each chinampero can work about three quarters of a hectare of chinampa per year (Jimenez-Osornio and del Amo, 1986), meaning that each farmer can support 12 to 15 people.

The use of polycultures is a common peasant strategy of minimizing risk by planting several species and varieties of crops which stabilizes yields over the long term, promotes diet diversity, and maximizes returns under low levels of technology and limited resources (Harwood, 1979). Much of the production of staple crops in the Latin American tropics occurs in polycultures. More than 40 percent of the cassava, 60 percent of the maize, and 80 percent of the beans in that region are grown in mixtures with each other or other crops (Francis, 1986). In most multiple cropping systems developed by smallholders, productivity in terms of harvestable products per unit area is higher than under sole cropping with the same level of management. Yield advantages can range from 20 percent to 60 percent. These differences can be explained by a combination of factors which include the reduction of losses due to weeds, insects and diseases and a more efficient use of the available resources of water, light and nutrients (Beets, 1982).

By the end of the twentieth century, peasant production units will have reached about 16 million occupying close to 160 million hectares, involving 75 million people representing almost two thirds of the Latin America's total rural population (Ortega, 1986). The overall contribution of peasant agriculture to the general food supply in the region is significant. In the 1980s it reached approximately 41 percent of the agricultural output for domestic consumption, and is responsible for producing at the regional level 51 percent of the maize, 77 percent of the beans, and 61 percent of the potatoes.

Applying Agroecology to Enhance the Productivity and Sustainability of Peasant Agriculture

In Latin America, economic change, fueled by capital and market penetration, is leading to an ecological breakdown that is starting to destroy the sustainability of traditional agriculture. After creating resource-conserving systems for centuries, traditional cultures in areas such as Mesoamerica, the Amazon, and the Andes are now being undermined by external political and economic forces. Biodivesity is decreasing on farms, soil degradation is accelerating, community and social organizations are breaking down, genetic resources are being eroded and traditions lost. Under this scenario, and given commercial pressures and urban demands, many developers argue that the performance of subsistence agriculture is unsatisfactory, and that intensification of production is essential for the transition from subsistence to commercial production (Blauert and Zadek, 1998). In reality the challenge is to guide such transition in a way that yields and income are increased without threatening food security, raising the debt of peasants, and further exacerbating environmental degradation. Many agroecologists contend that this can be done by generating and promoting resource conserving technologies, a source of which are the very traditional systems that modernity is destroying (Altieri, 1991).

Taking traditional farming knowledge as a starting point, a quest has begun in the developing world for affordable, productive, and ecologically sound small scale agricultural alternatives. In many ways, the emergence of agroecology stimulated a number of non-governmental organizations (NGOs) and other institutions to actively search for new kinds of agricultural development and resource management strategies that, based on local participation, skills and resources, have enhanced small farm productivity while conserving resources (Thrupp, 1996). Today there are hundreds of examples where rural producers in partnership with NGOs and other organizations, have promoted and implemented alternative, agroecological development projects which incorporate elements of both traditional knowledge and modern agricultural science, featuring resource-conserving yet highly productive systems, such as polycultures, agroforestry, and the integration of crops and livestock etc.

STABILIZING THE HILLSIDES OF CENTRAL AMERICA

Perhaps the major agricultural challenge in Latin America is to design cropping systems for hillside areas, that are both productive and reduce erosion. Several organizations have taken on this challenge with initiatives that emphasize the stewardship of soil resources, utilization of local resources, and inputs produced on farm.

Since the mid 1980s, the private voluntary organization World Neighbors has sponsored an agricultural development and training program in Honduras to control erosion and restore the fertility of degraded soils. Soil conservation practices were introduced-such as drainage and contour ditches, grass barriers, and rock walls-and organic fertilization methods were emphasized, such as chicken manure and intercropping with legumes. Program yields tripled or quadrupled from 400 kilograms per hectare to 1,200-1,600 kilograms, depending on the farmer. This tripling in per-hectare grain production has ensured that the 1,200 families participating in the program have ample grain supplies for the ensuing year. Subsequently, COSECHA, a local NGO promoting farmer-to-farmer methodologies on soil conservation and agroecology, helped some 300 farmers experiment with terracing, cover crops, and other new techniques. Half of these farmers have already tripled their corn and bean yields; 35 have gone beyond staple production and are growing carrots, lettuce, and other vegetables to sell in the local markets. Sixty local villagers are now agricultural extensionists and 50 villages have requested training as a result of hearing of these impacts. The landless and near-landless have benefited with the increase in labor wages from US $2 to $3 per day in the project area. Out-migration has been replaced by inmigration, with many people moving back from the urban slums of Tegucigalpa to occupy farms and houses they had previously abandoned, so increasing the population of Guinope. The main difficulties have been in the marketing of new cash crops, as structures do not exist for vegetable storage and transportation to urban areas (Bunch, 1987).

In Cantarranas, the adoption of velvetbean (*Mucuna pruriens*), which can fix up to 150 kg N/ha as well as produce 35 tones of organic matter per year, has tripled maize yields to 2500 kg/ha. Labor requirements for weeding have been cut by 75 percent and herbicides eliminated entirely. The focus on village extensionists was not only more efficient and less costly than using professional extensionists, it also helped to build local capacity and provide crucial leadership experience (Bunch, 1990).

Throughout Central America, CIDDICO and other NGOs have promoted the use of grain legumes to be used as green manure, an inexpensive source of organic fertilizer to build up organic matter. Hundreds of farmers in the northern coast of Honduras are using velvet bean (*Mucuna pruriens*) with excellent results, including corn yields of about 3,000 kg/ha, more than double the national average, erosion control, weed suppression and reduced land preparation costs. The velvet beans produce nearly 30 t/ha of biomass per year, or about 90-100 kg of N/ha per year (Flores, 1989). Taking advantage of well established farmer to farmer networks such as the *campesino a campesino* movement in Nicaragua and elsewhere, the spread of this simple technology has occurred rapidly. In just one year, more than 1000 peasants recovered degraded land in the Nicaraguan San Juan watershed (Holtz-Gimenez, 1996). Economic analyses of these projects indicate that farmers adopting cover cropping have lowered their utilization of chemical fertilizers (from 1.900 kg/ha to 400 kg/ha) while increasing yields from 700 kg to 2,000 kg/ha, with production costs about 22 percent lower than farmers using chemical fertilizers and monocultures (Buckles *et al.*, 1998).

Scientists and NGOs promoting slash/mulch systems based on the traditional "tapado" system, used on the Central American hillsides, have also reported increased bean and maize yields (about 3,000 kg/ha) and considerable reduction in labor inputs as cover crops smother aggressive weeds, thus minimizing the need for weeding. Another advantage is that the use of drought resistant mulch legumes such as *Dolichos lablab* provide good forage for livestock (Thurston *et al.*, 1994). These kinds of agroecological approaches are currently being used on a relatively small percentage of land, but as their benefits are being recognized by farmers, they are spreading quickly. Such methods have strong potential and offer important advantages for other areas of Central America and beyond.

Soil Conservation in the Dominican Republic

Several years ago, Plan Sierra, an ecodevelopment project, took on the challenge of breaking the link between rural poverty and environmental degradation in the central cordillera of the Dominican Republic. The strategy consisted of developing alternative production systems for the highly erosive conucos used by local farmers. Controlling erosion in the Sierra is not only important for the betterment of the life of these farmers but also represents hydroelectric potential as well as an additional 50,000 hectares of irrigated land in the downstream Cibao valley (Altieri, 1990).

The main goal of Plan Sierra's agroecological strategy was the development and diffusion of production systems that provided sustainable yields without degrading the soil thus ensuring farmers reasonable productivity and food self-sufficiency. More specifically, the objectives were to allow farmers to more efficiently use local resources such as soil moisture and nutrients, crop and animal residue, natural vegetation, genetic diversity, and family labor. In this way it would be possible to satisfy basic family needs for food, firewood, construction materials, medicinals, income, and so on.

From a management point of view, the strategy consisted of a series of farming methods integrated in several ways: 1. Soil conservation practices such as terracing, minimum tillage, alley cropping, living barriers, and mulching; 2. Use of leguminous trees and shrubs such as *Gliricidia*, *Calliandra*, *Canavalia*, *Cajanus*, and *Acacia* planted in alleys, for nitrogen fixation, biomass production, green manure, forage production, and sediment capture; 3. Use of organic fertilizers based on the optimal use of plant and animal residues; 4. Adequate combination and management of polycultures and/or rotations planted in contour and optimal crop densities and planting dates; 5. Conservation and storage of water through mulching and water harvesting techniques.

In various farms animals, crops, trees, and/or shrubs, are all integrated to result in multiple benefits such as soil protection, diversified food production, firewood, improved soil fertility, and so on. Since more than 2000 farmers have adopted some of the improved practices an important task of Plan Sierra was to determine the erosion reduction potential of the proposed systems. This proved difficult because most of the available methods to estimate erosion are not applicable for measuring soil loss in farming systems managed by resource-poor farmers under marginal conditions. Given the lack of financial resources and research infrastructure at Plan Sierra it was necessary to develop a simple method using measuring sticks to estimate soil loss in a range of concucos including those traditionally managed by farmers and the "improved ones" developed and promoted by Plan Sierra.

Based on field data collected in 1988-1989 on the accumulated erosion rates of three traditional and one improved farming system, the alternative systems recommended by Plan Sierra exhibited substantially less soil loss than the traditional shifting cultivation, cassava and guandul monocultures. The positive performance of the agroecologically improved conuco seemed related to the continuous soil cover provision through intercropping, mulching, and rotations, as well as the shortening of the slope and sediment capture provided by alley cropping and living barriers (Altieri, 1990).

RECREATING INCAN AGRICULTURE

Researchers have uncovered remnants of more than 170,000 hectares of "ridged-fields" in Surinam, Venezuela, Colombia, Ecuador, Peru, and

Bolivia (Denevan, 1995). Many of these systems apparently consisted of raised fields on seasonally-flooded lands in savannas and in highland basins. In Peru, NGOs have studied such pre-Columbian technologies in search of solutions to contemporary problems of high altitude farming. A fascinating example is the revival of an ingenious system of raised fields that evolved on the high plans of the Peruvian Andes about 3000 years ago. According to archeological evidence these Waru-Warus platforms of soil surrounded by ditches filled with water were able to produce bumper crops despite floods, droughts, and the killing frost common at altitudes of nearly 4000 meters (Erickson and Chandler, 1989).

In 1984 several NGOs and state agencies created the Proyecto Interinstitucional de Rehabilitacion de Waru-Warus (PIWA) to assist local farmers in reconstructing ancient systems. The combination of raised beds and canals has proven to have important temperature moderation effects extending the growing season and leading to higher productivity on the Waru-Warus compared to chemically fertilized normal pampa soils. In the Huatta district, reconstructed raised fields produced impressive harvest, exhibiting a sustained potato yield of 8-14 t/ha/yr. These figures contrast favorably with the average Puno potato yields of 1-4 t/ha/yr. In Camjata the potato fields reached 13 t/ha/yr and quinoa yields reached 2 t/ha/yr in Waru-Warus. It is estimated that the initial construction, rebuilding every ten years, and annual planting, weeding, harvest and maintenance of raised fields planted in potatoes requires 270 person-days/ha/yr. Clearly, raised beds require strong social cohesion for the cooperative work needed on beds and canals. For the construction of the fields, NGOs organized labor at the individual, family, multi-family, and communal levels.

Elsewhere in Peru, several NGOs in partnership with local government agencies have engaged in programs to restore abandoned ancient terraces. For example, in Cajamarca, in 1983, EDAC-CIED together with peasant communities initiated an all-encompassing soil conservation project. Over ten years they planted more than 550,000 trees and reconstructed about 850 hectares of terraces and 173 hectares of drainage and infiltration canals. The end result is about 1,124 hectares of land under construction measures (roughly 32% of the total arable land), benefiting 1,247 families (about 52% of the total in the area). Crop yields have improved significantly. For example, potato yields went from 5 t/ha to 8 t/ha and oca yields jumped from 3 to 8 t/ha. Enhanced crop production, fattening of cattle and raising of alpaca for wool, have increased the income of families from an average of $108 per year in 1983 to more than $500 today (Sanchez, 1994).

In the Colca valley of southern Peru, PRAVTIR (Programa de Acondicionamiento Territorial y Vivienda Rural) sponsors terrace reconstruction by offering peasant communities low-interest loans and seeds or other inputs to restore large areas (up to 30 hectares) of abandoned terraces. The advantages of the terraces is that they minimize risks in terms of frost and/or drought, reducing soil loss, broadening cropping options because of the microclimatic and hydraulic advantages of terraces, thus improving productivity. First year yields from new bench terraces showed a 43-65% increase of potatoes, maize, and barley, compared to the crops grown on sloping fields (table 1). The native legume *Lupinus mutabilis* is used as a rotational or associated crop on the terraces; it fixes nitrogen, which is available to companion crops, minimizing fertilizer needs and increasing production. One of the main constraints of this technology is that it is highly labor intensive. It is estimated that it would require 2,000 worker-days to complete the reconstruction of 1 hectare, although in other areas reconstruction has proven less labor intensive, requiring only 300-500 worker/day/ha (Treacey, 1989).

NGOs have also evaluated traditional farming systems above 4000 msnm, where maca (*Lepidium mevenii*) is the only crop capable of offering farmers secure yields. Research shows that maca grown in virgin soils or fallowed between 5-8 years, exhibited significantly higher yields (11.8 and 14.6 t/ha respectively) than maca grown after bitter potatoes (11.3 t/ha). NGOs now are advising farmers to grow maca in virgin or fallow soils in a rotative pattern, to use areas not suitable for other crops and taking advantage of the local labor and low costs of the maca-based system (UNDP, 1995; Altieri, 1996).

Table 1. *First year per hectare yields of crops on new bench terraces, compared to yields on sloping fields* (kg/ha).

Crop[a]	Terraced[b]	Non-Terraced[c]	Percent Increase	N[d]
Potatoes	17,206	12,206	43	71
Maize	2,982	1,807	65	18
Barley	1,910	1,333	43	56
Barley (forage)	23,000	25,865	45	159

[a] All crops treated with chemical fertilizers.
[b] Water absorption terraces with earthen walls and inward platform slope.
[c] Fields sloping between 20 and 50 percent located next to terraced fields for control.
[d] N = number of terrace/field sites.
Source: Treacey 1984.

ORGANIC FARMING IN THE ANDES

In the Bolivian highlands, average potato production is falling despite a 15 percent annual increase in the use of chemical fertilizers. Due to increases in the cost of fertilizer, potato farmers must produce more than double the amount of potatoes compared with previous years to buy the same quality of imported fertilizer (Augstburger, 1983). Members of the former Proyecto de Agrobiologia de Cochabamba, now called AGRUCO, are attempting to reverse this trend by helping peasants recover their production autonomy. In experiments conducted in neutral soils, higher yields were obtained with manure than with chemical fertilizers. In Bolivia, organic manures are deficient in phosphorous. Therefore, AGRUCO recommends phosphate rock and bone meal, both of which can be obtained locally and inexpensively, to increase the phosphorous content of organic manures. To further replace the use of fertilizers and meet the nitrogen requirements of potatoes and cereals, intercropping and rotational systems have been designed that use the native species *Lupinus mutabilis*. Experiments have revealed that *L. mutabilis* can fix 200 kg of nitrogen per hectare per year, which becomes partly available to the associated or subsequent potato crop, thus significantly minimizing the need for fertilizers (Augstburger, 1983). Intercropped potato/lupine overyielded corresponding potato monocultures, and also substantially reduced the incidence of virus diseases.

Other studies in Bolivia, where Lupine has been used as a rotational crop, show that although yields are greater in chemically fertilized and machinery-prepared potato fields, energy costs are higher and net economic benefits lower than with the agroecological system (table 2). Surveys indicate that farmers prefer this alternative system because it optimizes the use of scarce resources, labor and available capital, and is available to even poor producers (Rist, 1992).

AGROECOLOGICAL APPROACHES IN BRAZIL

The state government extension and research service, EPAGRI (Empresa de Pesquisa Agropecuaria e Difusao de Technologia de Santa Catarina), works with farmers in the southern Brazilian state of Santa Catarina. The technological focus is on soil and water conservation at the micro-watershed level using contour grass barriers, contour ploughing and green manures. Some 60 cover crop species have been tested with farmers, including both leguminous plants such as velvetbean, jackbean, lablab, cowpeas, many vetches and crotalarias, and non-legumes such as oats and

Table 2. *Performance of traditional, modern, and agroecological potato-based production systems in Bolivia.*

	Traditional low-input	Modern high-input	Agroecological system
Potato yields (metric tons/ha)	9.2	17.6	11.4
Chemical fertilizer ($N + P_2O_5$, kg/ha)	0.0	80 + 120	0.0
Lupine biomass (metric tons/ha)	0.0	0.0	1.5
Energy efficiency (output/input)	15.7	4.8	30.5
Net income per Invested Boliviano	6.2	9.4	9.9

Source: Rist 1992.

turnips. For farmers these involved no cash costs, except for the purchase of seed. These are intercropped or planted during fallow periods, and are used in cropping systems with maize, onions, cassava, wheat, grapes, tomatoes, soybeans, tobacco, and orchards (Monegat, 1991).

The major on-farm impacts of the project have been on crop yields, soil quality and moisture retention, and labor demand. Maize yields have risen since 1987 from 3 to 5 t/ha and soybeans from 2.8 to 4.7 t/ha. Soils are darker in color, moist and biologically active. The reduced need for most weeding and ploughing has meant significant labor savings for small farmers. From this work, it has become clear that maintaining soil cover is more important in preventing erosion than terraces or conservation barriers. It is also considerably cheaper for farmers to sustain. EPAGRI has reached some 38,000 farmers in 60 micro-watersheds since 1991 (Guijt, 1998). They have helped more than 11,000 farmers develop farm plans and supplied 4300 tons of green manure seed.

In the savannahs of the Brazilian Cerrados, where soybean monoculture dominates, many problems associated with inappropriate land development have become evident. A key to production stability in the Cerrados is soil conservation and soil fertility replenishment as maintenance and increase of soil organic content is of paramount importance. For this reason NGOs and government researchers have concentrated efforts on the design of appropriate crop rotation and minimum tillage systems. The adoption of maize-soybean rotations have increased yields, slowed soil erosion and decreased pest and disease problems that affected soybean monocrops. Better weed control as well as soil organic maintenance has also been observed in such rotational systems (Spehar and Souza, 1996).

Another promoted alternative technique has been the use of green manures such as *Crotalaria juncea* and *Stizolobium atterrimum*. Researchers have shown grain crops following green manure yielded up to 46% more than monocultures during normal rainy seasons. Although the most common way of using green manures is to plant a legume after the main crop has been harvested, green manures can be intercropped with long cycle crops. In the case of maize – green manure intercrop, best performance is observed when *S. atterrimum* is sown 30 days after the maize. Maize can also be intercropped with perennial pasture legumes such as *Zornia* sp and *Stylosanthes* spp, a system of double purpose: produces food and fodder (Spehar and Souza, 1996).

Integrated Production Systems

A number of NGOs promote the integrated use of a variety of management technologies and practices. The emphasis is on diversified farms in which each component of the farming system biologically reinforces the other components; for instance, where wastes from one component become inputs to another. Since 1980, CET, a Chilean NGO, has engaged in a rural development program aimed at helping peasants reach year-round food self sufficiency while rebuilding the productive capacity of their small land holdings (Altieri, 1995). The approach has been to set up several 0.5 ha model farms, which consist of a spatial and temporal rotational sequence of forage and row crops, vegetables, forest and fruit trees, and animals. Components are chosen according to crop or animal nutritional contributions to subsequent rotational steps, their adaptation to local agroclimatic conditions, local peasant consumption patterns and finally, market opportunities. Most vegetables are grown in heavily composted raised beds located in the garden section, each of which can yield up to 83 kg of fresh vegetables per month, a considerable improvement to the 20-30 kg produced in spontaneous gardens tended around households. The rest of the 200-square meter area surrounding the house is used as an orchard, and for animals, (cows, hens, rabbits, and langstroth behives).

Vegetables, cereals, legumes and forage plants are produced in a six year rotational system within a small area adjacent to the garden. Relatively constant production is achieved (about six tons per year of useful biomass from 13 different crop species) by dividing the land into as many small fields of fairly equal productive capacity as there are years in the rotation. The rotation is designed to produce the maximum variety of basic crops in six plots, taking advantage of the soil-restoring properties and biological control features of the rotation.

Over the years, soil fertility in the original demonstration farm has improved, and no serious pest or disease problems have appeared. Fruit trees in the orchard and fencerows, as well as forage crops are highly productive. Milk and egg production far exceeds that on conventional farms. A nutritional analysis of the system based on its key components shows that for a typical family it produces a 250% surplus of protein, 80 and 550% surplus of vitamin A and C, respectively, and a 330% surplus of calcium. A household economic analysis indicates that, the balance between selling surpluses and buying preferred items provides a net income beyond consumption of US $ 790. If all of the farm output were sold at whole sale prices, the family could generate a monthly net income 1.5 times greater than the monthly legal minimum wage in Chile, while dedicating only a relatively few hours per week to the farm. The time freed up is used by farmers for other on-farm or off-farm income generating activities.

In Cuba. the Asociacion Cubana de Agricultura Organica (ACAO), a non-governmental organization formed by scientists, farmers, and extension personnel, has played a pioneering role in promoting alternative production modules (Rosset, 1997). In 1995, ACAO helped establish three integrated farming systems called "agroecological light houses" in cooperatives (CPAs) in the province of Havana. After the first six months, all three CPAs had incorporated agroecological innovations (i.e. tree integration, planned crop rotation, polycultures, green manures, etc.) to varying degrees, which, with time, have led to enhancement of production and biodiversity, and improvement in soil quality, especially organic matter content. Several polycultures such as cassava-beans-maize, cassava-tomato-maize, and sweet potato-maize were tested in the CPAs. Productivity evaluation of these polycultures indicates 2.82, 2.17 and 1.45 times greater productivity than monocultures, respectively.

The use of *Crotalaria juncea* and *Vigna unguiculata* as green manure have ensured a production of squash equivalent to that obtainable applying 175 kg/ha of urea. In addition, such legumes improved the physical and chemical characteristics of the soil and effectively broke the life cycles of insect pests such as the sweet potato weevil (SANE, 1998).

At the Cuban Instituto de Investigacion de Pastos, several agroecological modules with various proportions of the farm area devoted to agriculture and animal production were established. Monitoring of production and efficien-

Table 3. *Productive and efficiency performance of the 75% animal / 25% crop integrated module in Cuba.*

Productive Parameters	1st Year	3rd Year
Area (ha)	1	1
Total Production (t/ha)	4.4	5.1
Energy Produced (Mcal/ha)	3797	4885
Protein Produced (Kg/ha)	168	171
Number of people fed by one ha.	4	4.8
Inputs (energy expenditures, Mcal)		
- Human Labor	569	359
- Animal Work	16.8	18.8
- Tractor Energy	277.3	138.6

Source: SANE 1998.

cies of a 75% pasture / 25% crop module, reveals that total production increases over time, and that energy and labor inputs decrease as the biological structuring of the system begins to sponsor the productivity of the agroecosystem. Total biomass production increased from 4.4 to 5.1 t/ha after 3 years of integrated management. Energy inputs decreased, which resulted in enhanced energy efficiency from (4.4 to 9.5) (table 3). Human labor demands for management also decreased over time from 13 hours of human labor/day to 4-5 hours. Such models have been promoted, extensively in other areas through field days and farmers cross visits (SANE, 1998).

CONCLUSION

Most research conducted on traditional and peasant agriculture in Latin America suggests that small holder systems are sustainably productive, biologically regenerative, and energy-efficient, and also tend to be equity enhancing, participative, and socially just. In general, traditional agriculturalists have met the environmental requirements of their food-producing systems by relying on local resources plus human and animal energy, thereby using low levels of input technology.

While it may be argued that peasant agriculture generally lacks the potential of producing meaningful marketable surplus, it does ensure food security (table 4; Altieri, 1995). In fact, most agroecological technologies

Table 4. *Extent and impacts of agroecological technologies and practices implemented b NGOs in peasant farmin systems throughout Latin America.*

Country	Organization Involved	Agroecological Intervention	No. of Farmers or Farming Units Affected	No. of Hectares Affected	Dominant Crops	Yield (%)
Brazil	EPAGRI AS-PTA	Green Manures Cover Crops	38,000 Families	1,330,000	Maize Wheat	198-
Guatemala	Altertec and Others	Soil Conservation Green Manures Organic Farming	17,000 Units	17,000	Maize	250%
Honduras	CIDDICO COSECHA	Soil Conservation Green Manures	27,000 Units	42,000	Maize	250%
El Salvador	COAGRES	Rotations Green Manures Compost Botanicals	>200 Farmers	nd	Cereals	40-6
Mexico	Oaxacan Cooperatives	Compost Terracing Compost Planting	3,000 Families	23,500	Coffee	140%
Peru	PRAVTIR CIED	Rehabilitation of Ancient Terraces	>1250 Families	>1000	Andean Crops	141-
	PIWA-CIED	Raised Fields	nd	250	Andean Crops	333%
	CIED	Watershed Agricultural Rehabilitation	>100 Families	N/A	Andean Crops	30-5
	IDEAS	Intercropping Agroforestry Composting	12 Families	25	Several Crops	20%
Dominician Republic	Plan Sierra Swedforest-Fudeco	Soil Conservation Dry Forest Mgmt. Silvopastoral Systems	>2,500 Families	>1,000	Several Crops	50-7
Chile	CET	Integrated Farms Organic Farming	>1,000 Families	>2,250	Several Crops	>50%
Cuba	ACAO	Integrated Farms	4 Cooperatives	250	Several Crops	50-7

Nd = no data.
Source: Browder 1989, Altiere 1195, Pretty 1997.

promoted by NGOs can improve traditional agricultural yields increasing output per area of marginal land from some 400-600 kg/ha to 2000-2500 kg/ha enhancing also the general agrodiversity and its associated positive effects on food security and environmental integrity. Some projects emphasizing green manures and other organic management techniques can increase maize yields from 1-1.5 t/ha (a typical highland peasant yield) to 3-4 t/ha. Polycultures produce more combined yield in a given area than could be obtained from monocultures of the component species. Most traditional or NGO promoted polycultures exhibit LER values greater than 1.5. Moreover, yield variability of cereal/legume polycultures are much lower than for monocultures of the components.

In general, data shows that over time agroecological systems exhibit more stable levels of total production per unit area than high-input systems; produce economically favorable rates of return; provide a return to labor and other inputs sufficient for a livelihood acceptable to small farmers and their families; and ensure soil protection and conservation as well as enhance biodiversity.

For a region like Latin America, which is considered to be 52.2 percent self-reliant on major food crops as it produces enough food to satisfy the needs of its population, agroecological approaches that can double yields of the existing 16 million peasant units can safely increase the output of peasant agriculture for domestic consumption to acceptable levels well into the future. To address hunger and malnutrition, however, it is not only necessary to produce more food, but this must be available for those who need it most. Land redistribution is also a key prerequisite in order for peasants to have access to acceptable land and thus perform their role in regional self-reliance.

REFERENCES

Altieri, M.A. (1990): 'Stabilizing Hillside Farming System in the Sierra of Dominican Republic' (IAHS-AISH Pub No 192), pp. 355-363.

Altieri, M.A. (1991): 'Traditional Farming in Latin America', *The Ecologist*, 21, pp. 93-96.

Altieri, M.A., and Hecht, S.B. (1991): *Agroecology and Small Farm Development* (CRC Press, Boca Raton).

Altieri, M.A., and Masera, O. (1993): 'Sustainable Rural Development in Latin America: Building from the Bottom up', *Ecological Economics*, 7, pp. 93-121.

Altieri, M.A. (1995): *Agroecology: the Science of Sustainable Agriculture* (Westview Press, Boulder).

Altieri, M.A. (1996): *Enfoque Agroecologico para el Desarrollo de Sistemas de Produccion Sostenibles en los Andes* (Centro de Investigacion, Educacion y Desarrollo, Lima).

Altieri, M.A., Rosset, P., and Thrupp, L.A. (1998): *The Potential of Agroecology to Combat Hunger in the Developing World* (*2020 Brief.* IFPRI, Washington, D.C.).

Augstburger, F. (1983): 'Agronomic and Economic Potential of Manure in Bolivian Valleys and Highlands', *Agric. Ecosystem Environ.*, 10, pp. 335-346.

Blauert, J., and Zadek, S. (1998): *Mediating Sustainability* (Kumarian Press, Connecticut).

Buckles, D., Triomphe, B., and Sain, G. (1998): *Cover Crops in Hillside Agriculture* (IDRC-CIMMYT, Mexico D.F.).

Bunch, R. (1987): 'Case Study of the Guinope Integrated Development Program', *Proceedings IIED Conference on Sustainable Development* (London).

Bunch, R. (1990): 'Low-input Soil Restoration in Honduras: the Cantarranas Farmer-to-Farmer Extension Project', in *Sustainable Agriculture Gatekeeper Series* (SA23.IIED, London).

Denevan, W.M. (1995): 'Prehistoric Agricultural Methods as Models for Sustainability', *Advanced Plant Pathology*, 11, pp. 21-43.

Erickson, C.L., and Chandler, K.L. (1989): 'Raised Fields and Sustainable Agriculture in Lake Titicaca Basin of Peru', in J.O. Browder (ed.), *Fragile Lands of Latin America* (Westview Press, Boulder), pp. 230-243.

Flores, M. (1989): 'Velvetbeans: an Alternative to Improve Small Farmers' agriculture', *ILEIA Newsletter*, 5, pp. 8-9.

Francis, C.A. (1986): *Multiple Cropping Systems* (MacMillan, New York).

Gliessman, S.R. (1998): *Agroecology: Ecological Process in Sustainable Agriculture* (Ann Arbor Press, Michigan).

Guijt, I. (1998): 'Assessing the Merits of Participatory Development of Sustainable Agriculture: Experiences from Brazil and Central America', in J. Blauert and S. Zadek (eds.), *Mediating Sustainability* (Kumarian Press, Conn.), pp. 100-128.

Harwood, R.R. (1979): *Small Farm Development – Understanding and Improving Farming Systems in the Humid Tropics* (Westview Press, Boulder).

Holtz-Gimenez, E. (1996): 'The Campesino a Campesino Movement: Farmer-led, Sustainable Agriculture in Central America and Mexico', in *Food First Development Report* No. 10 (Institute of Food and Development Policy, Oakland).

Jimenez-Osornio, J., and del Amo, S. (1986): 'An Intensive Mexican Traditional Agroecosystem: the Chinampa', *Proc. 6th International Scientific Conference IFOAM*, Santa Cruz, California.

Monegat, C. (1991): *Plantas de Cobertura del Suelo* (CIDDICO, Honduras).

Ortega, E. (1986): *Peasant Agriculture in Latin America* (Joint ECLAC/FAO Agriculture Division, Santiago).

Posner, J.L., and McPherson, M.F. (1982): 'Agriculture on the Steep Slopes of Tropical America', *World Development*, 10, pp. 341-53.

Pretty, J. (1995): *Regenerating Agriculture* (World Resources Institute, Washington, D.C.).

Pretty, J. (1997): 'The Sustainable Intensification of Agriculture', *Natural Resources Forum*, 21, pp. 247-256.

Rist, S. (1992): 'Ecologia Economia y Technologia Campesina', *Ruralter*, 10, pp. 205-227.

Rosset, P.M. (1997): 'Alternative Agriculture and Crisis in Cuba', *Technology and Society*, 16, pp. 19-25.

Sanchez, J.B. (1994): 'A Seed for Rural Development: the Experience of EDAC-CIED in the Mashcon Watershed of Peru', *Journal of Learnings*, 1, pp. 13-21.

Sanders, W.T. (1957): *Tierra y Agua: a Study of the Ecological Factors in the Development of Meso-American Civilizations* (PhD Dissertation, Harvard University).

SANE (1998): *Farmers, NGOs and Lighthouses: Learning from Three Years of Training, Networking and Field Activities* (SANE-UNDP, Berkeley).

Spehar, C.R., and Souza, P.I.M. (1996): 'Sustainable Cropping Systems in the Brazilian Cerrados', *Integrated Crop Management*, 1, pp. 1-26.

Thrupp, L.A. (1996): *New Partnerships for Sustainable Agriculture* (World Resources Institute, Washington, D.C.).

Thurston H.D. *et al.* (1994): *Slash/Mulch: How Farmers use it and What Researchers Know About it* (CIIFAD-CATIE, Ithaca, N.Y.).

Treacey, J.M. (1989): 'Agricultural Terraces in Peru's Colca Valley: Promises and Problems of an Ancient Technology', in J.O. Browder (ed.), *Fragile Lands of Latin America* (Westview Press, Boulder).

UNDP (1995): *Benefits of Diversity* (UNDP, New York).

THE POTENTIAL OF SMALL FARM AGRICULTURE TO MEET FUTURE FOOD NEEDS

PETER ROSSET

INTRODUCTION

Our global food system is in the midst of a multifaceted crisis, with ecological, economic, and social dimensions that threaten our ability to meet food needs in the twenty-first century. The current food system is productive – there should be no doubt about that – as *per capita* food produced in the world has increased by 15 percent over the past thirty-five years (Lappé *et al.*, 1998). But as that production is in ever fewer hands, and costs ever more in economic and ecological terms, it has become harder to address basic problems of hunger and food access in the short term, let alone in a sustainable fashion. In the last twenty years the number of hungry people in the world – excluding China – has risen by 60 million (Lappé *et al.*, 1998).

Ecologically, there are impacts of industrial-style farming on groundwater through pesticide and fertilizer runoff, on biodiversity through the spread of monoculture and a narrowing of the genetic base of key food crops, and on the very capacity of agroecosystems to be productive into the future. Economically, production costs have risen as farmers are forced to use ever more expensive machines and farm chemicals, while crop prices continue a several-decade-long downward trend, causing a cost-price squeeze which has led to the loss of untold tens of millions of farmers worldwide to bankruptcies. Socially, there is a crisis of concentration of farmland in fewer and fewer hands, as low crop prices make farming on a small scale unprofitable (despite higher per acre total productivity of small farms), and agribusiness corporations extend their control over more and more basic commodities (Lappé *et al.*, 1998).

Clearly the dominant corporate food system is not capable of adequately addressing the needs of people or of the environment. I marshal evidence in this chapter which shows that an alternative, small farm, family-based production model could create the conditions for meeting future food needs in a more environmentally sustainable and socially just manner. Yet there are substantial obstacles to the widespread adoption of an alternative model. The greatest obstacles are presented by political-corporate power and vested interests, yet at times the psychological barrier to believing that the alternatives can work seems almost as difficult to overcome. This paper is dedicated to showing that by moving toward small farm agriculture we *could* meet future food needs.

For more than a century mainstream economists in both capitalist and socialist countries have confidently and enthusiastically predicted the demise of the small, family farm. Small farms have time and again been labeled as backward, unproductive and inefficient – an obstacle to be overcome in the process of economic development. The American model of large scale, mechanized, corporate agriculture is held out as the best, if not the only way to efficiently feed the world's population. Small farmers – or "peasants" – have been expected to go the way of the dinosaurs, and rightly so, according to conventional wisdom.

In this chapter I challenge that conventional wisdom about small farms and assert that they are "multi-functional" – more productive, more efficient, and contribute more to economic development than large farms. I also argue that small farmers make better stewards of natural resources, conserving biodiversity and better safe-guarding the sustainability of production.

I include evidence for both the Third World and for industrialized countries like the United States. Although this volume emphasizes developing countries, we must recognize that the dominant global agricultural paradigm has largely been exported to them from the United States and other Northern countries. This technology transfer has been accompanied by ideological baggage which asserts that anything larger and more technified is better. In responding to this assertion – which has been labeled a 'myth' (Lappé *et al.*, 1998) – it is important to show that it does not even hold true in its area of origin.

Today's on-going process of liberalization in international agricultural trade is widely recognized to have dramatically negative effects on small farmers in both Northern and Southern countries (Lappé *et al.*, 1998). This puts the small farm issue – called *The Agrarian Question* by renowned social scientist Karl Kautsky at the beginning of this century[1] – squarely on the agenda for debate at the end of the millennium.

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[1] Kautsky, 1906.

If small farms are worth preserving – if indeed a small farm model of rural development makes more sense than the large-scale, mechanized, chemical intensive, corporate dominated and socially excluding model toward which business-as-usual is carrying us – then now is the time to act.

The first point worth noting is that while small farmers have been driven out of rural America by the millions, and we have seen a similar, though lessor rural-urban migration in developing countries, the fact is that family farmers do still persist in the U.S. and continue to be numerically dominant. In the Third World they are central to the production of staple foods. The prediction of their demise continues to be premature, though their numbers have dropped substantially and they face new threats to their livelihoods on an unprecedented scale.

The second point is that small farms are far from being as unproductive or inefficient as so many economists would have us believe, as peasants have stubbornly clung to the land despite more than a century of harsh policies which have undercut their viability. There is ample evidence that a small farm model for agricultural development could produce far more food than a large farm pattern ever could.

The third point is that small farms have multiple functions which benefit both society and the biosphere, and go far beyond simply producing a particular commodity in their importance. These beneficial functions should be seriously valued and considered before we blithely accept yet another round of anti-small farm policy measures – this time at the level of the global economy. It is toward the second and third points – the benefits of small farms, that I direct the bulk of this paper.

In the conclusions I outline the grave threat to small farms presented by the "Millennium Round" negotiations under the World Trade Organization, which begin in the fall of 1999. Several countries, led by the United States, seek to push free trade in agricultural products. I show how this could lead to the destruction of small farms and severely damage rural environment worldwide.

We should recognize and value the multiple functionality of small farms, for both human societies and for the biosphere. By recognizing the true roles played by small farms we have a chance to stop and even reverse the trade and other policies that erode the viability of small farms.

Small Farm Virtues in the U.S.

I am not alone in speaking to the value of small farms and calling for policy change to take advantage of their potential dynamism. The United States Department of Agriculture's National Commission on Small Farms released a landmark report in 1998 titled *A Time to Act*. What the USDA calls the *public value of small farms* includes:

(a) *Diversity:* small farms embody a diversity of ownership, of cropping systems, of landscapes, of biological organization, culture and traditions. A varied farm structure contributes to biodiversity, a diverse and esthetically pleasing rural landscape, and open space.

(b) *Environmental benefits:* responsible management of the natural resources of soil, water, and wildlife on the 60 percent of all U.S. farms less than 180 acres in size, produces significant environmental benefits for society. Investment in the viability of these operations will yield dividends in the stewardship of the nation's natural resources.

(c) *Empowerment and community responsibility:* decentralized land ownership produces more equitable economic opportunity for people in rural areas, as well as greater social capital. This can provide a greater sense of personal responsibility and feeling of control over one's life, characteristics that are not as readily available to factory line workers. Land owners who rely on local businesses and services for their needs are more likely to have a stake in the well-being of the community and the well-being of its citizens. In turn, local land owners are more likely to be held accountable for any negative actions that harm the community.

(d) *Places for families:* family farms can be nurturing places for children to grow up and acquire values. The skills of farming are passed from one generation to another under family ownership structures. When farm children do not return to farming, a generation of farming knowledge, skills and experience is lost.

(e) *Personal connection to food:* most consumers have little connection to agriculture and food production. As a consequence, they have little connection with nature, and lack an appreciation for farming as cultivation of the earth for the production of food that sustains us. Through farmers' markets, community supported agriculture, and the direct marketing strategies of small farmers, consumers are beginning to connect with the people growing their food, and with food itself as a product of a farmer's cooperation with nature.

(f) *Economic foundations:* in various states and regions of the U.S., small farms are vital to the economy.

The USDA Commission on Small Farms concludes with a powerful call to change the policies that have favored large, corporate-style farms for so very long, with hideous costs to rural communities and the environment.

Small Farm Virtues in the Third World

A similar pattern holds in the Third World, where policies promoting large farm, export agriculture have increasingly eroded the viability of small farms, despite the many benefits small scale production of foodstuffs offers.

In traditional farming communities the family farm is central to the maintenance of community and the sustainability of agricultural production. On the small farm, productive activities, labor mobilization, consumption patterns, ecological knowledge and common interests in long-term maintenance of the farm as a resource, contribute to a stable and lasting economic and family-based enterprise. Work quality, management, knowledge and relationships are intertwined and mutually reinforcing. Short term gain at the risk of degrading essential resources not only invites community sanction, but also places the family and the farm at risk of collapse. Family farmers regularly achieve higher and more dependable production from their land than do large farms operating in similar environments. Labor intensive practices such as manuring, limited tillage, ridging, terracing, composting organic matter, and recycling plant products into the productive process, enhance soil conservation and fertility (Netting, 1993).

The durability of small farm production is clear in its historical and spatial ubiquity: small farms exist in all environments, in all political and economic contexts, in all historical periods over the last 5,000 years, and in every known cultural area where crops can be grown. Small farmers have developed and use a variety of technologies, crops, and farming systems. Perhaps most important in an era of diminishing non-renewable resources, small farmers frequently produce with minimal recourse to expensive external inputs (Netting, 1993).

We must value the multiple functions of farms in the Third World if we are to achieve a sustainable agriculture, according to the Food and Agriculture Organization (FAO) of the United Nations (1999):

> To face the current challenges of agriculture, we need to address agriculture and land in a broader context by integrating multiple roles (economic, food production, nature and land management, employment etc.). Sustainable agriculture and land use is not just a means to obtain more food and income, in socially acceptable ways which do not degrade the environment. Rather, it has an all-encompassing impact on communities, environments, and consumers. We must reach a consensus and common understanding of sustainable land use as an opportunity to improve the quality of the environment, including its physical (increased soil fertility, better quality air and water), biological (healthier and more diverse animal, plant, and human populations), and social, economic and institutional (greater social equity, cohesion, peace/stability, well-being) compo-

> nents… Land is not just a resource to be exploited, but a crucial vehicle for the achievement of improved socioeconomic, biological and physical environments. Concretely, by paying attention to the multiple functions of agriculture and land use, all economic, social and environmental functions of agriculture, at multiple levels, are recognized and included in decision making in order to promote synergies between these functions and to reconcile different stakeholder objectives.

Just as in the case of the United States, small farms play key multiple functions in rural economies, cultures and ecosystems. In the following sections I summarize some of the evidence for these claims.

SMALL FARM PRODUCTIVITY

How many times have we heard that large farms are more *productive* than small farms? Or that they are more *efficient*? And that we need to consolidate land holdings to take advantage of that greater productivity and efficiency? The actual data show exactly the reverse for productivity: that smaller farms produce far more per unit area than larger farms. Part of the problem lies in the confusing language used to compare the performance of different farm sizes. As long as we use crop *yield* as *the* measure of productivity, we will be giving an unfair advantage to larger farms.

Total Output versus Yield

If we are to fairly evaluate the relative productivity of small and large farms, we must discard "yield" as our measurement tool. Yield means the production per unit area of a single crop, like "metric tons of corn per hectare". One can often obtain the highest yield of a single crop by planting it alone on a field – in a monoculture. But while a monoculture may allow for a high yield of one crop, it produces nothing else of use to the farmer. The bare ground between the crop rows – empty "niche space" in ecological terms – invites weed infestation. The presence of weeds makes the farmer invest labor in weeding or capital in herbicide.

Large farmers tend to plant monocultures because they are the simplest to manage with heavy machinery. Small farmers on the other hand, especially in the Third World, are much more likely to plant crop mixtures – intercropping – where the empty niche space that would otherwise produce weeds instead is occupied by other crops. They also tend to combine or rotate crops and livestock, with manure serving to replenish soil fertility. Such integrated farming systems produce far more per unit area than do monocultures. Though the yield per unit area of one crop – corn, for example – may be lower on a small farm than on a large monoculture, the total output per unit area, often composed of more than a dozen crops and various animal products, can be far, far higher. Therefore, if we are to compare small and large farms we should use *total output*, rather than yield. Total output is the sum of everything a small farmer produces: various grains, fruits, vegetables, fodder, animal products, etc. While yield almost always biases the results toward larger farms, total output allows us to see the true productivity advantage of small farms.

Surveying the data we indeed find that small farms almost always produce far more agricultural output per unit area than larger farms. This holds true whether we are talking about an industrial country like the United States, or any country in the Third World. This is now widely recognized by agricultural economists across the political spectrum, as the "inverse relationship between farm size and output" (Barret, 1993; Ellis, 1993; Tomich *et al.*, 1995; Berry and Cline, 1979; Feder, 1985; Prosterman and Riedinger, 1987; Cornia, 1985; to name a few). Even leading development economists at the World Bank have come around to this view, to the point that they now accept that re-distribution of land to small farmers would lead to greater overall productivity (Deininger, 1999; Binswanger *et al.*, 1995), a view long since arrived at by others (see Sobhan, 1993; Lappé *et al.*, 1998). Table 1 shows the relationship

Table 1. *Farm Size versus Output in the United States, 1992.*

Median Farm Size Category (Acres)	Average Gross Output ($/Acre)	Average Net Output ($/Acre)
4	7424	1400
27	1050	139
58	552	82
82	396	60
116	322	53
158	299	55
198	269	53
238	274	56
359	270	54
694	249	51
1364	191	39
6709	63	12

Source: U.S. Agricultural Census, vol. 1, part 51, pp. 89-96, 1992.

between farm size and ouput per acre in the United States. The smallest farms, those of 27 acres or less, have more than ten times greater dollar output per acre than larger farms. While this is in large part due to the fact that smaller farms tend to specialize in high value crops like vegetables and flowers, it also reflects relatively more labor and inputs applied per unit area, and the use of more diverse farming systems (Strange, 1988).

Figure 1 graphically shows the relationship between farm size and total output for 18 Third World countries. In all cases relatively smaller farm sizes are from 200 to 1,000% productive per unit area than are larger ones. We observe two general forms of the relationship, as shown in figure 2. Curve I is found in countries where the smallest reported farm size category is the most productive per unit area. Curve II is found where the most productive size category, while not *the* smallest, is still *relatively* small. All countries for which data is available fit one of these two types. The data presented in table 1, from the U.S., clearly matches type I.

There are a variety of explanations for the ubiquitousness of the greater productivity of small farms in the Third World (Netting, 1993; Lappé *et al.*, 1998). Some of these are:

a. *Multiple cropping*: as explained above, while large farmers almost always use monocultures, and one or at the most two cropping cycles per year, small farmers are more likely to intercrop various crops on the same field, plant multiple times during the year, and integrate crops, livestock and even aquaculture, making much more intensive use of space and time.

b. *Land use intensity*: larger farmers and land owners tend to leave much of their land idle, while small farmers tend to use their entire parcel.[2]

c. *Output composition*: large farms are oriented toward land extensive enterprises, like cattle grazing or extensive grain monocultures, while small farmers emphasize labor and resource intensive use of land. As in the U.S. case, large farms may produce crops with lower value than do smaller farms.

d. *Irrigation*: small farmers may make more efficient use of irrigation.

e. *Labor quality*: while small farms generally use family labor – which is personally committed to the success of the farm – large farms use relatively alienated hired labor.

f. *Labor intensity*: small farms apply far more labor per unit area than do small farms.

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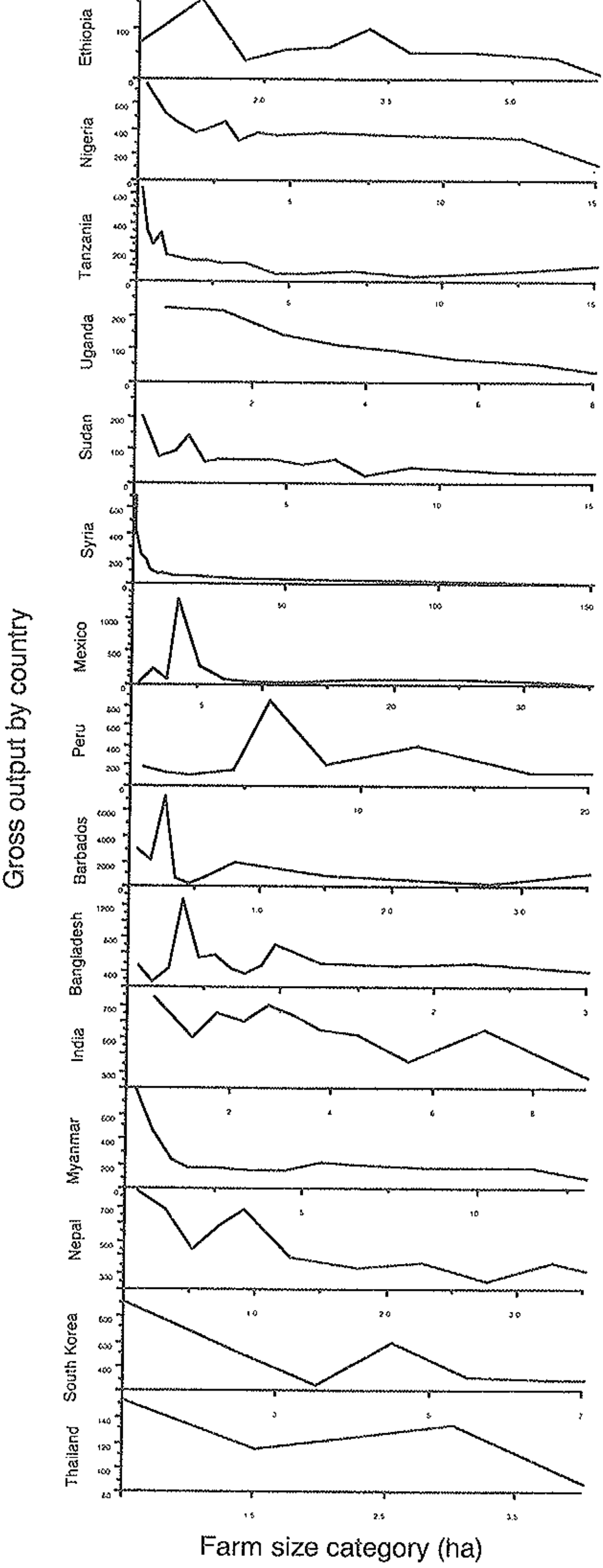
[2] In the U.S. the relationship is reversed. Small farms tend to have a lower intensity of land use, leaving greater proportions of their land in woodland, cover crops, etc. (S'Souza and Ikerd, 1996).


Gross output by country
Ethiopia
Nigeria
Tanzania
Uganda
Sudan
Syria
Mexico
Peru
Barbados
Bangladesh
India
Myanmar
Nepal
South Korea
Thailand
Farm size category (ha)

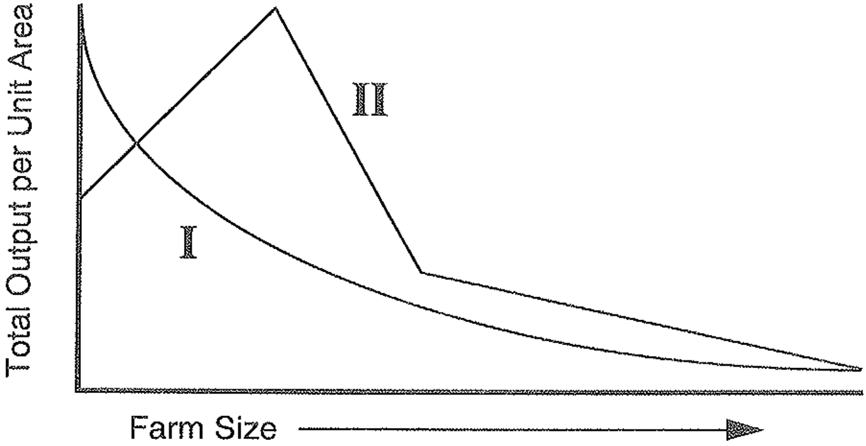


Fig. 2. Typical forms of the relationship between farm size and total output. In Type I the smallest farm sizes produce the most total output per unit area. In Type II the most productive size class is not the smallest, but is still relatively small. These idealized types have been abstracted from the data presented graphically in Appendix 1.

g. *Input use*: small farms often use far more inputs per unit area than larger farms, though the mix on small farms favors non-purchased inputs like manure and compost while large farms tend to use relatively more purchased inputs like agrochemicals.

h. *Resource use*: large farms are generally less committed to management of other resources – such as forests and aquatic resources – which combine with the land to produce a greater quantity and better quality of production.

It is the commitment that family members have to their farm, and the complexity and integrated nature of small farms, that guarantee their advantage in terms of output. Pretty (1997) has documented the productivity of such systems in a wide variety of environments.

Small Farm Efficiency

While small farms are clearly more productive than large farms in terms of output per unit area, claims are often made that large farms are still *more efficient*. To start with, this depends on the definition of efficiency that one chooses. Small farms make more efficient use of land. Large farms generally have higher labor productivity due to mechanization, so they might be considered to be more efficient in labor usage. The definition of efficiency most widely accepted by economists is that of "total factor productivity", a sort of averaging of the efficiency of use of all the different factors that go into production, including land, labor, inputs, capital, etc. Tomich *et al.* (1995, p. 126) provide data from the 1960s, 70s and early 80s, which show small farms have greater total factor productivity than large farms in Sub-Saharan Africa, Asia, Mexico and Columbia. The curves follow the same patterns, Types I or II, shown in figure 2 for farm size vs. output. More recently, the same pattern has been found in Honduras (Gilligan, 1998).

In industrial countries like the U.S. the pattern is less clear. The consensus position is probably that very small farms are inefficient because they can't make full use of expensive equipment, while very large farms are also inefficient because of management and labor problems inherent in large operations. Thus peak efficiency is likely achieved on mid-sized farms that have one or two hired laborers, giving the U.S. an efficiency curve like the Type II productivity curve, but with the peak more toward mid-size than small (Strange, 1988, pp. 80-81; see also Madden, 1967). In a recent, detailed analysis of true total factor productivity, corrected for a number of biases in the data, the author concludes that advantages to larger farm sizes found by some analysts "disappear, while there is evidence of diseconomies as farm size increases" (Peterson, 1997). In other words, even in the United States, there is no reason to believe that large farms are more efficient, and very large farms may in fact be quite inefficient. But there is far more to the economic importance of small farms once we move outside the farm gate and ask questions about economic development.

Small Farms in Economic Development

Surely more bushels of grain is not the only goal of farm production; farm resources must also generate wealth for the overall improvement of rural life – including better housing, education, health services, transportation, local business diversification, and more recreational and cultural opportunities.

Here in the United States, the question was asked more than a half-century ago: what does the growth of large-scale, industrial agriculture mean for rural towns and communities? Walter Goldschmidt's classic 1940's study of California's San Joaquin Valley compared areas dominated by large corporate farms with those still characterized by smaller, family farms (see Goldschmidt, 1978).

In farming communities dominated by large corporate farms, nearby towns died off. Mechanization meant that fewer local people were employed, and absentee ownership meant that farm families themselves were no longer to be found. In these corporate-farm towns, the income earned in agriculture was drained off into larger cities to support distant enterprises, while in towns surrounded by family farms, the income circulated among local business establishments, generating jobs and community prosperity. Where family farms predominated, there were more local businesses, paved streets and sidewalks, schools, parks, churches, clubs, and newspapers, better services, higher employment, and more civic participation. Studies conducted since Goldschmidt's original work confirm that his findings remain true today (see Fujimoto, 1977; MacCannell, 1988; Durrenberger and Thu, 1996).

The Amish and Mennonite farm communities found in the eastern United States provide a strong contrast to the virtual devastation described by Goldschmidt in corporate farm communities. Lancaster County in Pennsylvania, which is dominated by these small farmers who eschew much modern technology and often even bank credit, is the most productive farm county east of the Mississippi river. It has annual gross sales of agricultural products of $700 million, and an receives an additional $250 million from tourists who appreciate the beauty of traditional small farm landscapes (D'Souza and Ikerd, 1996). Ludwig and Anderson (1992) argue that Amish farm communities provide a North American model for what they call "indigenous development", essentially an emphasis on building a strong local economy as the basis for participating in the larger world:

> The *vision* of indigenous development is one of global *inter*-dependence through the *intra*-dependence of semiautonomous regions. Instead of placing emphasis on the highest or global level of competitive interaction, it starts at the bottom and places emphasis on the development of strong, independent, semiautonomous regions with unique identities ... Many of the Amish communities, separated by self-defined boundaries, are ... self-reliant. These [are] interesting examples because their economies are market oriented and highly successful; they do substantial trade with the outside; they are great husbands of the natural environment; and their members find a great deal of meaning and centeredness in their work. While their economies are market based, they are highly diverse and integrated rather than fragmented, cooperative rather than competitive, based on value added rather than on commodity products, and dedicated to reciprocity more than dominance (p. 35).

If we turn toward the Third World we find similar local benefits to be derived from a small farm economy. The Landless Workers Movement

(MST) is a grassroots organization in Brazil that helps landless laborers to organize occupations of idle land belonging to wealthy landlords (Langevin and Rosset, 1999). When the movement began in the mid-1980s, the mostly conservative mayors of rural towns were violently opposed to MST land occupations in surrounding areas. In recent times, however, their attitude has changed. Most of their towns are very depressed economically, and occupations can give local economies a much needed boost. Typical occupations consist of 1,000 to 3,000 families, who turn idle land into productive farms. They sell their produce in the marketplaces of the local towns and buy their supplies from local merchants. Not surprisingly those towns with nearby MST settlements are now better off economically than other similar towns, and many mayors now actually petition the MST to carry out occupations near their towns (Candido Gryzbowski, IBASE, personal communication).

It is clear that local and regional economic development benefits from a small farm economy, as do the life and prosperity of rural towns. Can we re-create a small farm economy in places where it has been lost, in order to improve the wellbeing of the poor?

Improving Social Welfare Through Land Reform

Recent history shows that the re-distribution of land to landless and land-poor rural families can be a very effective way to improve rural welfare. Sobhan (1993) examined the outcome of virtually every land reform program carried out in the Third World since World War II. He is careful to distinguish between what he calls 'radical' re-distribution (called 'genuine land reform' by Lappé *et al.*, 1998), and 'non-egalitarian' reforms (or 'fake land reform' in the Lappé *et al.*'s terminology). When quality land was really distributed to the poor, and the power of the rural oligarchy to distort and 'capture' policies broken, real, measurable poverty reduction and improvement in human welfare has invariably been the result. Japan, South Korean, China, Taiwan and China are all good examples. In contrast, countries with reforms that gave only poor quality land to beneficiaries, and/or failed to alter the rural power structures that work against the poor, have failed to make a major dent in rural poverty. Mexico and the Philippines are typical cases of the latter (Sobhan, 1993; Lappé *et al.*, 1998).

While Sobhan looked at national-level statistics to derive his conclusions, Besley and Burgess (1998) recently looked at the history of land reform in 16 individual Indian states from 1958 to 1992. While these were by and large not radical reforms in Sobhan's sense, many did abolish tenancy and reduce the importance of intermediaries. The authors found a strong relationship between land reform and the reduction of poverty. Similarly in Brazil, land reform beneficiaries and members of MST-settlements have a higher standard of living than those families who remain landless (Candido Gryzbowski, IBASE, personal communication). In fact land reform holds promise as a means to stem the rural-urban migration that is causing Third World cities to grow beyond the capacity of urban economies to provide enough jobs.

In Brazil IBASE, a social and economic research center, studied the impact on government coffers of legalizing MST-style land occupations-*cum*-settlements versus the services used by equal numbers of people migrating to urban areas. When the landless poor occupy land and force the government to legalize their holdings, it implies costs: compensation of the former landowner, legal expenses, credit for the new farmers, etc. Nevertheless the total cost to the state to maintain the same number of people in an urban shanty town – including the services and infrastructure they use – exceeds in just one month, the yearly cost of legalizing land occupations (Candido Gryzbowski, IBASE, personal communication).

Another way of looking at it is in terms of the cost of creating a new job. Estimates of the cost of creating a job in the commercial sector of Brazil range from 2 to 20 times more than the cost of establishing an unemployed head of household on farm land, through agrarian reform. Land reform beneficiaries in Brazil have an annual income equivalent to 3.7 minimum wages, while still landless laborers average only 0.7 of the minimum. Infant mortality among families of beneficiaries has dropped to only half of the national average (Stédile, 1998).

This provides a powerful argument that land reform to create a small farm economy is not only good for local economic development, but is also more effective social policy than allowing business-as-usual to keep driving the poor out of rural areas and into burgeoning cities.

Sobhan (1993) argues that *only* land reform holds the potential to address chronic underemployment in most Third World countries. Because small farms use more labor – and often less capital – to farm a given unit of area, a small farm model can absorb far more people into gainful activity and reverse the stream of out-migration from rural areas. What of national economic development? How do countries characterized by small farms fare compared to those dominated by large farms?

National Economic Development and 'Bubble-Up' Economics

In turns out that a relatively equitable, small farmer-based rural economy does provide the basis for strong national economic development. This "farmer road to development" is part of the reason why, early on in its history, the United States developed more rapidly and evenly than Latin America, with its inequitable land distribution characterized by huge haciendas and plantations interspersed with poverty-stricken subsistence farmers (de Janvry, 1981). In the United States, independent "yeoman" farmers formed a vibrant domestic market for manufactured products from urban areas, including farm implements, clothing and other necessities. This domestic demand fueled economic growth in the urban areas, and the combination gave rise to broad-based growth (Sachs, 1987).

More recently the post-war experiences of Japan, South Korea and Taiwan demonstrate how equitable land distribution fuels economic development. At the end of the war circumstances, including devastation and foreign occupation, conspired to create the conditions for 'radical' land reforms in each country, breaking the economic stranglehold of the landholding class over rural economic. Combined with trade protection to keep farm prices high, and targeted investment in rural areas, small farmers rapidly achieved a high level of purchasing power, which guaranteed domestic markets for fledging industries (Sachs, 1987).

The post-war economic 'miracles' of these three countries were each fueled at the start by these internal markets centered in rural areas, long before the much heralded 'export orientation' policies which much later on pushed those industries to compete in the global economy. This was real triumph for 'bubble-up' economics, in which redistribution of productive assets to the poorest strata of society created the economic basis for rapid development. It stands in stark contrast to the failure of 'trickle down' economics to achieve much of anything in the same time period in areas of U.S. dominance, such as much of Latin America (Sachs, 1987).

A further benefit of small farm development through land reform in East Asia was the dispersal of political power. Economically enfranchised small farmers became an important political base that politicians had to respond to, avoiding the kind of urban biases in policy-making that have sabotaged economic development in much of the Third World (Sachs, 1987).

More generally, there is now a growing consensus among mainstream development economists, long called for by those on the left, that inequality in asset distribution impedes economic growth (Solimano, 1999). This is leading even such institutions as the World Bank to call for land reform, albeit of a 'non-radical,' 'market-led' variety I do not necessarily endorse (see for example, Banerjee, 1998; Stiglitz, 1998; Deininger and Binswanger, 1998; for the alternative view, see complaints in Inspection Panel, 1999).

Ecosystem Services & Sustainability

The benefits of small farms extend beyond the economic sphere. Whereas large, industrial-style farms impose a scorched-earth mentality on resource management – no trees, no wildlife, endless monocultures – small farmers can be very effective stewards of natural resources and the soil. To begin with, small farmers utilize a broad array of resources and have a vested interest in their sustainability. At the same time, their farming systems are diverse, incorporating and preserving significant functional biodiversity within the farm. By preserving biodiversity, open space and trees, and by reducing land degradation, small farms provide valuable ecosystem services to the larger society.

In the United States, small farmers devote 17% of their area to woodlands, compared to only 5% on large farms. Small farms maintain nearly twice as much of their land in "soil improving uses", including cover crops and green manures (D'Souza and Ikerd, 1996). In the Third World, peasant farmers show a tremendous ability to prevent and even reverse land degradation, including soil erosion (Templeton and Scherr, 1999).

Many small farm agroecosystems in the Third World are are located on a wide variety of slopes, aspects, microclimates, elevational zones, and soil types. They are surrounded by many different vegetation associations. There are numerous combinations of diverse biophysical factors which have led to the diverse cropping patterns developed by farmers to exploit site-specific characteristics. Descriptions of the species and structural diversity and management of these traditional systems are found throughout the literature on agroecology (see for example, Altieri, 1995; Pretty, 1995; Netting, 1993; *The Ecologist*, 1998).

In many areas traditional farmers have developed and/or inherited complex farming systems which are highly adapted to local conditions, allowing them to sustainably manage production in harsh environments while meeting their subsistence needs, without depending on mechanization, chemical fertilizers, pesticides or other technologies of modern agricultural science (Altieri, 1995).

Compared to the ecological wasteland of a modern export plantation, the small farm landscape contains a myriad of biodiversity. The forested areas from which wild foods, and leaf litter are extracted, the wood lot, the farm itself with intercropping, agroforestry, and large and small livestock, the fish pond, the backyard garden, allow for the preservation of hundreds if not thousands of wild and cultivated species. Simultaneously, the commitment of family members to maintaining soil fertility on the family farm means an active interest in long-term sustainability not found on large farms owned by absentee investors.

If we are truly concerned about rural ecosystems, then the preservation and promotion of small, family farm agriculture is a crucial step we must take.

CONCLUSIONS

Throughout this paper I have examined the multiple functions played by small farms, and the myriad benefits they provide for society and for the biosphere. A small farm model has far greater productive potential than does today's large-scale, monoculture-based, corporate style of industrial farming. Smaller farms also provide many more opportunities to farm in an ecologically sustainable fashion.

Ending hunger should not mean destroying our environment or eating unsafe food. We have seen that a food system based on pesticides and, increasingly, genetic engineering, has failed to address hunger (Lappé *et al.*, 1998), while driving land concentration and ultimately, social exclusion, in rural areas, thus actually increasing hunger. The only path to increasing food production to meet future food needs which can end hunger, is to devise food systems in which those who do the work have a greater say and reap greater rewards. In other words, inequality -- the driving force between present day, and most likely future, hunger -- must be attacked simultaneously with effort to boost production. By emphasizing smaller farms we can do both.

Despite decades of anti-small farm policies taken by nation states, small farmers have clung to the soil in amazing numbers. But today we stand at a cross-roads. As a world we are poised to take steps toward global economic integration that pose far greater threats to small farmers than they have ever faced before.

Trade liberalization -- the move toward global free trade policies -- poses a grave threat to the continued existence of small farms throughout the world. Over the past couple of decades Third World countries have been encouraged, cajoled, threatened, and generally pressured into unilaterally reducing the level of protection offered to their domestic food producers in the face of well-financed foreign competitors. Through participation in GATT, NAFTA, the World Bank, the International Monetary Fund and the World Trade Organization, they have reduced or some cases eliminated tariffs, quotas and other barriers to unlimited imports of food products (Bello *et al.*, 1999). On the face of it, this might sound like a good thing. After all, more food imports might make food cheaper in poor, hungry countries, and thus make it easier for the poor to obtain enough to eat. However, the experiences of many countries suggest that there are downsides to these policies which may outweigh the potential benefits.

Typically Third World economies have been inundated with cheap food coming from the major grain exporting countries. For a variety of reasons (subsidies, both hidden and open, industrialized production, etc.) this food is more often than not put on the international market at prices below the local cost of production. That drives down the prices that local farmers receive for what they produce, with two related effects, both of which are negative (Lappé *et al.*, 1998).

First, a sudden drop in farm prices can drive already poor, indebted farmers off the land over the short term. Second, a more subtle effect kicks in. As crop prices stay low over the medium term, profits per unit area – per acre or hectare – stay low as well. That means the minimum number of hectares needed to support a family rises, contributing to abandonment of farm land by smaller, poorer farmers – land which then winds up in the hands of the larger, better off farmers who can compete in a low price environment by virtue of having very many hectares. They overcome the low profit per hectare trap precisely by owning vast areas which add up to good profits in total, even if they represent very little on a per hectare basis. The end result of both mechanisms is the further concentration of farm land in the ever fewer hands of the largest farmers (Lappé *et al.*, 1998).

A penalty is paid for this land concentration in terms of productivity, as large farmers turn to monocultures and machines to farm such vast tracts, and in terms of the environment, as these large mechanized monocultures come to depend on agrochemicals. Jobs are lost as machines replace human labor and draft animals. Rural communities die out as farmers and farm workers migrate to cities. Natural resources deteriorate as nobody is left who cares about them. Finally, food security is placed in jeopardy: domestic food production falls in the face of cheap imports; land that was once used to grow food is placed into production of export crops for distant markets; people now depend on money – rather than land – to feed themselves; and fluctuations in employment, wages and world food prices can drive millions into hunger.

This process should be a more or less familiar one to North Americans, who have seen low crop prices and the "get big or get out" mentality of government policy drive four million farmers off the land since World War II (Lappé *et al.*, 1998; Heffernan, 1999). We have paid, and continued to pay, a heavy price of runaway soil erosion from excessive mechanization and "fence row to fence row" planting, of urban problems because our inner cities never did absorb the excess labor expelled from rural America, and of the collapse of rural life.

The major drive to export grain from America's heartland, which began in the 1970s, contributed to a 40 percent increase in soil erosion in the corn and soybean belts. Today about 90 percent of U.S. crop land is losing topsoil faster than it can be replaced (Lappé *et al.*, 1998.) The export boom also contributed to a 25 percent increase in average farm size, which was accompanied by the loss of one third of all American farmers between 1970 and 1992 (U.S. Census of Agriculture, 1992). In a very real sense, then, the U.S. drive to dominate global grain markets has hurt family farmers and damaged rural ecosystems both at home and abroad.

What is euphemistically known as a "fair and market-oriented agricultural trading system" – almost totally free trade in farm products – is unfortunately the agenda of American negotiators at the World Trade Organization (Permanent Mission of the United States, 1999).

This represents the single gravest threat faced today by the world's rural peoples and ecologies. The further "liberalization" of trade in agricultural products would mean greater freedom for the big to drive out the small, for forcing people everywhere to depend on distant global markets – with unpredictable price swings – for the daily meals, another mass exodus from rural areas and the further growth of cities, and could lead to the final triumph of inefficient and ecologically destructive monocultures over ecologically rational and sustainable farming practices.

There is less than unanimous support among the world's nations for the U.S position. A number of countries have taken up the call made in Chapter 14 of Agenda 21, the declaration drawn up at the 1992 Earth Summit in Rio, that "agricultural policy review, planning and integrated programming [be carried out] in the light of the multifunctional aspects of agriculture, particularly with regard to food security and sustainable development".

According to this viewpoint, agriculture produces not only commodities, but also livelihoods, cultures, ecological services, etc., and as such, the products of farming cannot be treated in the same way as other goods. While a shoe, for example, is a relatively simple good whose world price can be set by supply and demand, and the trade in which can be regulated through tariffs or de-regulated by removing them, not so for farming, whose roles are far more complex.

The Japanese government, for example, has put it this way (Permanent Mission of Japan, 1999):

> Agriculture not only produces/supplies agricultural products, but also contributes to food security, by reducing the risks caused by unexpected events or a possible food shortage in the future, to the preservation of land and environment, to the creation of a good landscape and to the maintenance of the local community, through production

> activities in harmony with the natural environment. All of these roles are known as the "multifunctionality" of agriculture.
>
> The multifunctionality of agriculture has the following characteristics: (a) Most aspects of multifunctionality are regarded as economic externalities and it is difficult to reflect their values properly in market prices. Though it is closely related to production, it cannot be subject to trade; (b) Market mechanisms alone cannot lead to the realization of an agricultural production method that will embody the multifunctionality of agriculture.

Norway has also endorsed the concept of multifunctionality as the basis for special treatment of farming for reasons of environmental protection, food security and the viability of rural areas (Norwegian Ministry of Agriculture, 1998), as has the European Union to some extent (European Commission, 1999), and as have some other countries.

Ignoring the multiple functions of agriculture has caused untold suffering and ecological destruction in the past. The time is long overdue to recognize the full range of contributions that agriculture – and small farms in particular – make to human societies and to the biosphere. Farms are not factories that churn out sneakers or tennis racquets, and we cannot let narrow arguments of simple economic expediency destroy this legacy of all human kind.

Instead of deepening policies that damage small farms, we should implement policies to develop small farm economies. These might include genuine land reforms, tariff protection for staple foods – so that farmers receive fair prices, and the reversal of biases in policies for credit, technology, research, education, subsidies, taxes and infrastructure which unfairly advance large farms at the expense of smaller ones. By doing so we will strike at the root causes of poverty, hunger, underdevelopment and degradation of rural ecosystems.

REFERENCES

Altieri, M.A. (1995): *Agroecology: The Science of Sustainable Agriculture* (Boulder, Westview Press).

Banerjee, A. (1998): 'Why Wealth Distribution Can Matter for Growth: A Review of Key Issues' (Working Paper Summaries, International Conference on Asset Distribution, Poverty, and Economic Growth, Brasilia, Brazil, July 14-17, 1998, Available at http://www.worldbank.org/landpolicy/brazil/papers.htm).

Barret, C.B. (1993): 'On Price Risk and the Inverse Farm Size-Productivity Relationship', *University of Wisconsin-Madison, Department of Agricultural Economics Staff Paper Series* no. 369.

Bello, W., Cunningham, S., and Rau, B. (1999): *Dark Victory: The United States and Global Poverty.* Second Edition (Oakland, Food First Books).

Berry, R.A., and Cline, W.R. (1979): *Agrarian Structure and Productivity in Developing Countries* (Baltimore, Johns Hopkins University Press).

Besley, T., and Burgess, R. (1998): 'Land Reform, Poverty Reduction and Growth: Evidence from India' (Paper presented at the "Asset Distribution, Poverty and Economic Growth", International Conference, Brasilia, Brazil, July 14-17).

Binswanger, H.P., Deininger, K., and Feder, G. (1995): 'Power, Distortions, Revolt and Reform in Agricultural Land Relations', in J. Behrman and T.N. Srinivasan (eds.), *Handbook of Development Economics*, Volume III (Elsevier Science B.V.).

Carter, M.R. (1984): 'Identification of the Inverse Relationship between Farm Size and Productivity: An Empirical Analysis of Peasant Agricultural Production', *Oxford Economic Papers*, no. 36, pp. 131-145.

Cornia, G.A. (1985): 'Farm Size, Land Yields and the Agricultural Production Function: An Analysis for Fifteen Developing Countries', *World Development*, 13(4), pp. 513-534.

Deininger, K. (1999): *Making Negotiated Land Reform Work: Initial Experience from Columbia, Brazil and South Africa* (Washington, DC, The World Bank).

Deininger, K., and Binswanger, H. (1998): 'The Evolution of the Bank's Land Policy' (Washington, The World Bank, Mimeo).

De Janvry, A. (1981): *The Agrarian Question and Reformism in Latin America* (Baltimore, John Hopkins University Press).

D'Souza, G., and Ikerd, J. (1996): 'Small Farms and Sustainable Development: Is Small *More* Sustainable?', *Journal of Agricultural and Applied Economics*, 28(1), pp. 73-83.

Durrenberger, E.P., and Thu, K.M. (1996): ' The Expansion of Large-Scale Hog Farming in Iowa: The Applicability of Goldschmidt's Findings Fifty Years Later', *Human Organization*, 55(4), pp. 409-415.

Ellis, F. (1993): *Peasant Economics: Farm Households and Agrarian Development*, 2nd edition (Cambridge, Cambridge University Press).

European Commission (1999): 'The EU Approach to the Millennium Round' (Communication from the Commission to the Council and to the European Parliament. Brussels, European Commission, http://europa.eu.int/comm/dg01).

Feder, G. (1985): 'The Relationship between Farm Size and Farm Productivity', *Journal of Development Economics*, 18, pp. 297–313.

Food and Agriculture Organization, United Nations (FAO) (1999): *Cultivating our Futures: FAO/Netherlands Conference on the Multifunctional Character of Agriculture and Land. Scoping Phase. Synopsis: The Multiple Roles of Agriculture and Land* (Rome, Sustainable development Division of FAO).

Fujimoto, I. (1977): 'The Communities of the San Joaquin Valley: The Relationship between Scale of Farming, Water Use, and the Quality of Life' (Testimony before the House Subcommittee on Family Farms, Rural Development, and Social Studies, Sacra-mento, CA, October 28, 1977).

Gilligan, D.O. (1998): 'Farm Size, Productivity, and Economic Efficiency: Accounting for Differences in Efficiency by Size in Honduras' (Paper presented at the 1998 American Agricultural Economics Association Annual Meetings, Salt Lake City, Utah).

Goldschmidt, W. (1978): *As You Sow: Three Studies in the Social Consequences of Agribusiness* (New York, Allenheld, Osmun).

Heffernan, W. (1999): *Consolidation in the Food and Agriculture System. Report to the National Farmers Union* (Columbia, University of Missouri).

Inspection Panel, The World Bank (1999): *Request for Inspection. Brazil: Land Reform and Poverty Alleviation Pilot Project (Ln 447-BR). Panel Report and Recommendation. Annex 1* (Washington, The World Bank, INSP/R99-4).

Kautsky, K. (1906): *La Question Agraire* (Paris, Maspero).

Langevin, M.S., and Rosset, P. (1999): 'Land Reform from Below: The Landless Worker's Movement in Brazil', in D. Boucher (ed.), *The Paradox of Plenty: Hunger in a Bountiful World* (Oakland, Food First Books), pp. 323-329.

Lappé, F.M., Collins, J., Rosset, P., and Esparza, L. (1998): *World Hunger: Twelve Myths*, 2nd Edition (New York, Grove Press).

Ludwig, D.C., and Anderson, R.J. (1992): 'A Model of Indigenous Revival for U.S. Agriculture', *Journal of International Food & Agribusiness Marketing*, 4(2), pp. 23-39.

MacCannell, D., 'Industrial Agriculture and Rural Community Degradation', in L.E. Swanson (ed.), *Agriculture and Community Change in the U.S.: The Congressional Research Reports.* (Boulder, Westview Press), pp. 15-75.

Madden, J.P. (1967): *Economics of Size in Farming: Theory, Analytic Procedures, and a Review of Selected Studies* (Agricultural Economic report No. 107, Washington, DC, USDA Economic Research Service).

Netting, R.McC. (1993): *Smallholders, Householders: Farm Families and the Ecology of Intensive, Sustainable Agriculture* (Stanford, Stanford University Press).

Norwegian Ministry of Agriculture (1998): 'Non-Trade Concerns in a Multifunctional Agriculture - Implications for Agricultural Policy and the Multilateral Trading System' (Oslo, Ministry of Agriculture (ODIN-LD), http://odin.dep.no/landbruk/faktorare.html).

Permanent Mission of Japan (1999): *Negotiations on Agriculture: Communication from Japan* (Geneva, World Trade Organization, WT/GC/W/220).

Permanent Mission of the United States (1999): *Negotiations on Agriculture: Objective and Overall Framework for the Agricultural Negotiations. Communiction from the United States* (Geneva, World Trade Organization, WT/GC/W/18).

Peterson, W.L. (1997): 'Are Large Farms More Efficient?' (Staff Paper, Department of Applied Economics, University of Minnesota), pp. 92-7.

Pretty, J. (1995): *Regenerating Agriculture* (Washington, World Resources Institute).

Pretty, J. (1997): 'The Sustainable Intensification of Agriculture', *Natural Resources Forum*, 21, pp. 247-256.

Prosterman, R.L., and Riedinger, J.M. (1987): *Land Reform and Democratic Development* (Baltimore, Johns Hopkins University Press).

Sachs, J.D. (1987): 'Trade and Exchange Rate Policies in Growth Oriented Adjustment Programs', in V. Corbo, M. Goldstein and M. Khan (eds.), *Growth-Oriented Adjustment Programs* (Washington, DC, International Monetary Fund and The World bank), pp. 291-325.

Sobhan, R. (1993): *Agrarian Reform and Social Transformation: Preconditions for Development* London, Zed).

Solimano, A. (1999): 'Beyond Unequal Development: An Overview', Forthcoming in E. Aninat and N. Birdsall (eds.), *Distributive Justice and Economic Development* (Ann Arbor, University of Michigan Press).

Stédile, J.P. (1998): *Questão Agrária No Brasil. 6.ª Edição* (São Paulo, Editora Atual).

Stiglitz, J. (1998): 'Distribution, Efficiency and Voice: Designing the Second Generation of Reforms' (Working Paper Summaries, International Conference on Asset Distribution, Poverty, and Economic Growth, Brasilia, Brazil, July 14-17, 1998. Available at
http://www.worldbank.org/landpolicy/brazil/papers.htm).

Strange, M. (1988): *Family Farming: A New Economic Vision* (Lincoln, University of Nebraska Press and Food First Books).

Templeton, S.R., and Scherr, S.J. (1999): 'Effects of Demographic and Related Microeconomic Change on Land Quality in Hills and Mountains of Developing Countries', *World Development*, 27(6), pp. 903-918.

The Ecologist (1998): *Traditional Agriculture Dossier* (Surrey, *The Ecologist*).

Tomich, T.P., Kilby, P., and Johnston, B.F. (1995): *Transforming Agrarian Economies: Opportunities Seized, Opportunities Missed* (Ithaca, Cornell University Press).

United States Census Bureau (1992): *1992 Agricultural Census*.

United States Department of Agriculture (1998): *A Time to Act: A Report of the USDA National Commission on Small Farms* (USDA Miscellaneous Publication 1545).

INTERNATIONAL COOPERATION AND INTEGRATION IN AGRICULTURAL RESEARCH AND FOOD PRODUCTION

NYLE C. BRADY

More than at any time in history, we live in an interdependent world. A devaluation of the currency in Thailand triggers economic stress in Japan and other Asian countries, that in turn adversely affects economies throughout the world. We are suffering from a series of just such events at the present time. There is growing global interdependence among all nations, both those of the North and the South.

The gradual demise of international trade barriers is affecting agriculture perhaps as much as any other industry. As a result the well being of both producers and consumers of food products in one country become increasingly dependent on events in other countries. For example, a drought in China or in West Africa, or floods in Bangladesh or in the Mississippi Delta have implications for food supplies and prices all over the world. This interdependence has helped maintain reasonably stable food prices, preventing their skyrocketing during periods of local food shortages. Also, it has called attention to the essentiality of international cooperation on all aspects of food production and utilization.

The internet and worldwide web are revolutionizing the interaction among people of the world. Commercial banks, industry and other business concerns use them daily to communicate with each other as well as with their branch offices anywhere in the world. Several times a day I receive messages from scientists, educators, farm managers and farmers from Europe, Australia, South America, Asia and the U.S., all of whom have a common interest in trickle irrigation. They use a relatively inexpensive means of sharing information and expertise, and of solving problems. Such communications remind us of the importance of cooperation among nations and among people if those in the less well developed countries are to benefit from the emerging wonders of science.

HISTORICAL INTERNATIONAL INTERACTION IN SCIENCE

The history of science gives many examples of how the research of a scientist in one country utilized knowledge or methodologies he/she received from scientists in other countries. The discovery of the relationship between the electric current and magnetism, and the subsequent development of an electric generator is a case in point. Even though Faraday, a British physicist, is generally given credit for inventing a generator, published results of a number of scientists from Denmark, France, the United States, and elsewhere provided background information that stimulated the research that ultimately led to the discovery. Likewise, von Liebig's discovery that mineral nutrients are essential to life, Pasteur's formulation of the germ theory of diseases, Roentgen's discovery of X-rays, Madam Curie's radiation studies, and Waksman's discovery of streptomycin, all great contributions to human betterment, were not accomplished by isolated individuals. In most cases, knowledge of what others had done and were doing was built upon as new discoveries came into being. Furthermore, the new research results were quickly published and made available to colleagues around the world. The process involved the free exchange of information with others, without regard to nationality or social class.

It should be emphasized that the exchanges just described took place between scientists of the industrialized countries of the North. Until recently, most developing countries have not been able to support such research. Countries of the South have benefitted only as technologies were transferred from the North.

Dr. P.N. Tandon, president of the National Academy of Sciences of India, has pointed out the gap between the S and T efforts of the South and North (Tandon, 1998). He made reference to the 1994 Science Citation Index that showed only 2 percent of the scientific literature published in index journals is coming from scientists in the South where 80 percent of the world's people live. This imbalance argues for expanded research in low income countries, especially in fields not being covered by counterparts in the North. It also suggests the wisdom of collaborative research involving teams of scientists from the North and the South.

COLLABORATIVE RESEARCH IN AGRICULTURE

Collaboration among researchers has characterized the S and T systems that revolutionized agricultural production during the past century. Such collaboration was common even before the green revolution. I witnessed the federal/state collaborative research networks in the United States that were so effective in spreading the benefits of hybrid maize in the 1930s to 1950s. Similar smaller networks involved the improvements of forage and vegetable crops. These networks had two major characteristics in common – the free exchange of genetic materials, and the equally free exchange of research results. This meant that each collaborator could benefit from the findings of all other collaborators. It also meant that new genetic materials, including those provided by overseas collaborators, were freely available to everyone in the system.

Most of the networks dealt with genetic evaluation and utilization. The performance of different cultivars was constrained by climatic and soil variables, making it necessary to set up region-specific networks. Thus, hybrid maize varieties that performed well in the mid-western part of the United States were not suitable for farmers in the southeastern or northeastern parts of the country. Consequently, different networks were established in each region.

The Food and Agriculture Organization (FAO) has also taken steps on the international front to stimulate collaboration among scientists from different countries. For example, in the 1950s FAO organized a series of research and extension networks in different regions of the world to ascertain the response of different crops to chemical fertilizers. While these trials had some weaknesses because little scientific rigor was used in implementing them, they played a major role in bringing international attention to the need for plant nutrients and to the widespread deficiencies of some of the nutrients in many parts of the world.

Collaboration that Underpinned the Green Revolution

The creation of 17 international research centers starting with the International Rice Research Institute (IRRI) in the Philippines in 1960 provided a basis for unprecedented collaboration among agricultural scientists from throughout the world. Much of the success attributed to these IARCs in underpinning the green revolution is in fact due to their interaction with scientists from national agricultural research centers (NARCs), and to the work of the national scientists stimulated by this interaction.

In the genetic improvement area, this collaboration began with the joint collection and storage in germplasm banks of vast quantities of seeds of cultivars as well as wild accessions (figure 1). Several hundred thousand accessions of major food crops have been collected, evaluated and stored at low temperatures in these banks. While the germplasm banks and the rejuvena-

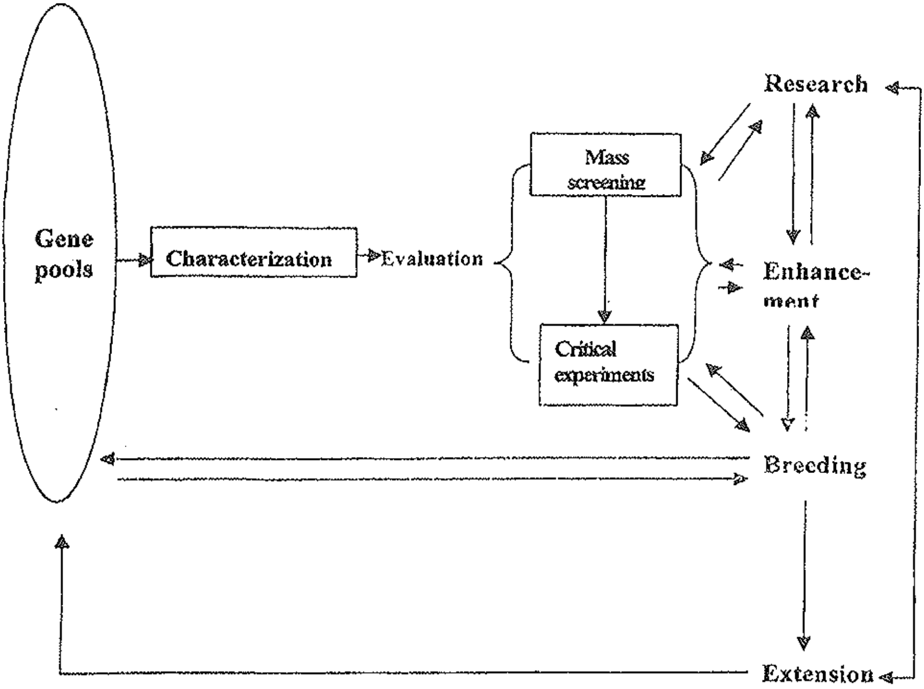


Fig. 1. The process of germplasm collection, evaluation and enhancement that underpinned the green revolution required extensive cooperation among scientists throughout the world. (From Chang, 1998).

tion of the collected seed were managed by the IARCs, samples of these genetic resources were freely exchanged with, not only the scientists who helped with the collection, but with other cooperators around the world. These gene banks are managed under guidelines developed jointly with FAO.

Two general types of cooperation pertained in the evaluation and utilization of the genetic materials collected. First, small scale cooperation involved researchers of two or more institutions on a very specific problem. Frequently one of the cooperators was from a research institute or university in the North with unusual expertise in the problem area. Perhaps she/he had developed a new technique to enhance crossing with a wild accession, or was experienced in a procedure such as embryo rescue methodology. The other cooperators were from the IARC and associated NARCs eager to utilize the new techniques.

Utilizing genetic resources from gene banks and elsewhere, the IARCs joined with scientists from national programs in setting up larger scale collaborative research networks in which hundreds of scientists participated. These networks involved the genetic improvement of different food crops with initial emphasis being given to wheat, rice and maize. Soon attention was given to sorghum, millet, beans and other edible legumes, cassava, potatoes, sweet potatoes, bananas and plantains. In recent years, fish genetics has also been included as a focal point for collaboration. In all cases the objectives were the same: to freely exchange genetic materials, to evaluate under a variety of environmental conditions the best materials from each of the network participants, and to freely exchange the results of the evaluation process.

Each collaborative research network had a number of characteristics that were determined by the collaborating partners. There was a common focus on priority issues, and a common set of research strategies and procedures that were developed by the group and not just by the IARC. Each collaborator agreed to openly exchange genetic materials and to share all the data obtained in the evaluation process. Thus a given cooperator learned from the network research how his lines and varieties fared under a wide variety of geographic and environmental conditions.

In most cases training mechanisms were established to be certain that all collaborators were able to the necessary procedures and analyses. A steering committee of collaborating scientists provided the general guidance for the network. They decided which yield and observational nurseries, as well as nurseries for specific stresses (e.g. diseases, insects, problem soils, cold temperatures etc.) were to be included in the overall network. The IARC generally served as the network coordinator with the responsibility for gathering appropriate seed samples of lines/varieties the scientists were offering for the tests, and organizing them into test lots that were then sent to each of the network cooperators. Figure 2 illustrates how the networks that were coordinated by IRRI operated.

The International Network for Genetic Evaluation of Rice (INGER), which has been operating since 1974, provides an example of a successful network. By 1997 some 1000 researchers from 95 countries and 4 IARCs had participated in the network programs. More than 42,000 lines/varieties had been evaluated in the INGER field trials. More than 625 lines included in the trials had been found to be sufficiently superior to be released as varieties. About half of these varieties were created in one country and released in another. Varieties that were developed in India or Sri Lanka, for example, were tested and released in Indonesia, the Philippines or Burma. Thus, considerable saving of research effort stemmed from the collaboration. The annual net worth of the new varieties coming from INGER collaboration may be as much as $1500 million.

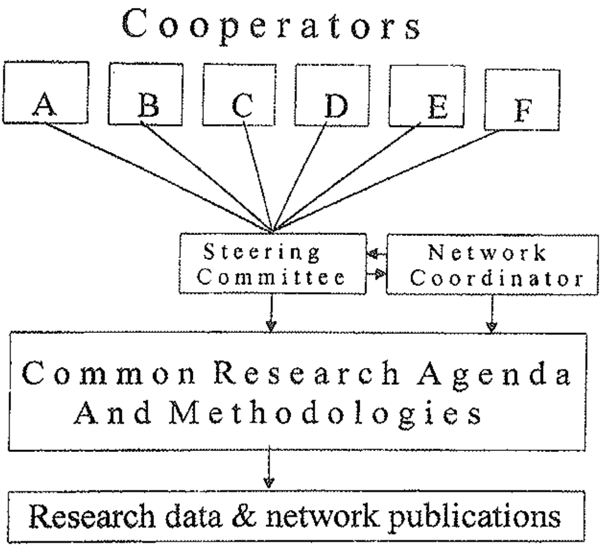


Fig. 2. Operational framework for the international collaborative rice research network that has been functioning since the early 1970s.

Similar collaborative research networks on wheat and maize have been just as productive. A recent study of the impact of the International Center for the Improvement of Wheat and Maize (CIMMYT) on the production of these two crops is impressive (CIMMYT, 1999). During the period 1991-97 90% of the spring bread wheat varieties, and 98% of the spring durum wheat varieties released by developing countries had ancestors supplied by CIMMYT. The collaborative research networks coordinated by CIMMYT were the primary mechanisms for making these genetic materials available.

DONOR COORDINATION

Agricultural progress in developing countries has greatly benefitted from the cooperation among financial supporters of agricultural research. The most notable example of such cooperation was the establishment of the Consultative Group on International Agricultural Research (CGIAR). In 1971 some 18 leaders from international organizations, foundations, and concerned governments of the North initiated this informal but nevertheless effective group. Its initial purpose was to support the research efforts of the five then existing international research centers (IARCs) whose objective was to use science to combat hunger and poverty in developing countries (CGIAR, 1998). Initially, the focus was on rice, wheat and maize, but in time other commodities and specific regional and natural resource opportunities were added (see table 1). By 1998 the number of IARCs supported by the CGIAR had increased to 16. They had scientists working in 100 countries, and had trained more than 50,000 collaborating scientists from developing countries (CGIAR, 1999).

Working with these and other scientists in developing countries, the system has achieved remarkable success. Partnerships with national counterparts have helped stimulate the 80 percent increase in global food output of the past 30 years, along with the 26 percent increase in caloric intake that has occurred in low income countries. Increased food production was accompanied by lower food costs, a significant benefit to the poor of both urban and rural areas. Furthermore, increased production on existing cultivated lands have made it unnecessary to clear for agricultural use some 300 million hectares of ecologically fragile lands that would have been needed to produce the extra food.

Donors have realized the effectiveness of the CGIAR-supported research, and have responded by increasing their funding. By 1998 annual contributions of $340 million were being made from 20 industrialized countries, 12 international or regional organizations, 3 foundations, and 18 developing countries. The developing country investment in this global effort is evidence of the wide confidence it enjoys.

Table 1. *Evolution in Time of the Research Agenda of International Agricultural Research Centers Funded by the CGIAR* (CGIAR, 1998).

Period	*Program expansion to include:*		
1960s	Rice	Wheat	Maize
Early 1970s	Tropic & Semi-arid tropics Roots & tubers	Livestock and pastures	Other cereals Legumes
Mid-1970s	Genetic resources	Dry areas	West African rice
1980s	Food Policy	Institutional strengthening	Institutional strengthening
1990s	Agro-Forestry & forestry	Natural resource management	Living aquatic resources

COLLABORATION ON NON-GENETIC RESEARCH

International agricultural research networks dealing with other than genetic improvement have also made significant contributions to increased food production and to sustainable agriculture. Networks concerned with cropping systems, soil fertility management, pest management, and natural resource management have done much to assure uniform high quality research, and to enhance the sharing of new knowledge. The networks commonly are interdisciplinary in nature, using the talents of scientists from several disciplines.

The Rice-Wheat Consortium for the Indo-Gangetic Plains is an example of a cooperative research effort instigated by developing countries. Stagnant or even declining yields of rice-wheat rotations in the Indo-Gangetic Plains led Bangladesh, India, Nepal and Pakistan to initiate the consortium, and to invite participation by several International Agricultural Research Centers (IARCs). Soil and water quality along with biotic factors such as insects, diseases and weeds are among the constraints being studied. A recent report of a conference on the effects of nematodes (Sharma *et al.*, 1998) is an example of the research underway, and of the exchange of information that the consortium encourages.

An example of donor cooperation in stimulating agricultural research in a region is the Special Program for African Agricultural Research (SPAAR). Established in 1985 by a group of donors, it now includes as members national, regional and international organizations concerned with agricultural research in Africa (SPAAR, 1998). SPAAR has helped establish and/or strengthen subregional research organizations for West Africa (CORAF), Southern Africa (SACCAR), and Central Africa (ASAREC), and has encouraged communications and networking. In spite of economic constraints in Africa and lowered priority for donor funding of agricultural projects, SPAAR has had some influence on the support and planning for agricultural research in Africa.

The development and evaluation of integrated pest management (IPM) systems are also the foci of collaborative regional and global research efforts (IITA, 1998). The CGIAR systemwide IPM program involves 12 international centers and dozens of national cooperators. Teams of scientists are working on specific pests such as white flies, potato weevil, stem borers, *Striga*, and geminiviruses.

Attention has been given in recent years, to the sustainability of production systems and particularly their effect on natural resource conservation and the well being of rural people. An example of a network dealing with these matters is the worldwide, interdisciplinary effort concerned with viable alternatives to slash and burn (ASB) agriculture (ICRAF, 1998). In 1992 scientists from several IARCs and NARS in Africa, Latin America and Asia initiated a cooperative program aimed at bettering the lot of "slash and burn" farmers while simultaneously protecting the environment. Some 9 IARCs and more than 100 national research institutes, universities and nongovernmental organizations have participated in the global effort. At benchmark sites in each of the three regions studies are underway to ascertain the effects of different farming alternatives on biodiversity, carbon dynamics and rural welfare.

Collaboration with Universities

Universities throughout the industrialized world are actively involved in international agricultural research. Often this involvement is because of mutual interest of a scientist in the North and his/her counterpart in the South. The growing need for coupling of upstream research with field-based evaluation sites encourages such North/South collaboration. In other cases, the cooperation at the institutional level is involved.

An example of North/South collaboration involving universities is the Collaborative Research Support Programs (CRSPs) of the United States. Initiated in the 1970s, CRSPs are jointly supported by collaborating US universities, the US Agency for International Development, and cooperating overseas research institutions. CRSPs have been established in areas ranging from crop and animal improvement and management (beans/cowpeas, sorghum/millet, peanuts, small ruminants) to fisheries, soil management, pest management, and sustainable agriculture (NAS, 1991). Linked in the overall system are some 2000 scientists from about 40 US universities, and 80 overseas research institutions.

Research findings of the CRSPs have benefitted both US and overseas citizens. For example, researchers have incorporated into crop plants resistance to diseases that have not yet reached the country in which the research is done. Hundreds of scientists and educators from overseas cooperating institutions have received training at US universities as part of the CRSP program.

Agroecological Models

As an alternative to the capital- and input-intensive model that characterized the green revolution, an agroecological model characterizes many recent cooperative research programs. Non governmental organizations (NGOs) and universities have led in conceptualizing this approach that emphasizes biodiversity, nutrient recycling, and natural resource conservation. (Altieri, 1996; Thrupp, 1997). Indigenous farmers and their local organizations are intimately involved with scientists and educators in planning and implementing the research. Researchers use a farmer's knowledge, and replace his/her practices only if the modern technology is clearly superior in terms of sustainable productivity.

The agroecological model shows much promise in less-favored areas where the green revolution was not effective and where land degradation has taken place. Some CGIAR-supported IARCs have initiated several ecoregional programs that focus on such areas, and that are using the farmer-based participatory research approach (table 2). Examples are the Ecological Program for Tropical Latin America and the Ecoregional Program for Humid and Sub-Humid Areas (CGIAR, 1998). The collaborative research teams for these programs include the producers and their organizations, local public and private leaders, national research and education leaders as well as scientists from the IARCs.

Table 2. *Inter-center Programs of International Agricultural Research Centers Supported by the CGIAR in 1998* (CGIAR, 1999).

Subject are of program focus	
Systemwide programs:	*Human and natural resources programs:*
– Genetic resources	– Alternatives to slash & burn agriculture
– Water management	– CGIAR gender & diversity
– Livestock	– Science for food, environment & world's poor
– Integrated pest management	– Farmer participatory research & gender analysis
– Property rights & collective action	– Soil, water & nutrient management
Ecoregional programs:	*Information programs:*
– Humid & subhumid areas	– Integrated voice and data network
– Tropical Latin America	– International crop information system
– Humid tropics & inlaud valley areas	– Information network on genetic resources
– Rice-wheat consortium for Indo-Gangetic plains	
– Desert margins	
– Mountainous areas	

INFORMATION EXCHANGE

Free and open exchange of information has always been a critical component of cooperative research programs. Such exchange built mutual confidence of each participant in genetic improvement networks that underpinned the green revolution. Free exchange of information is technically much easier today with the advent of the internet, e-mail, etc. Web sites of scientific journals are available to scientists in developing countries, and some libraries use the internet and e-mail to provide copies of articles requested by scientists in these countries.

Since 1983, scientists in the CGIAR system have communicated with each other through a CGNET system that now links more than 300 sites in some 100 countries (CGIAR, 1999). The CGIAR's web site (established in 1994) is visited by about 40,000 people monthly. Eight IARCs have established the International Crop Information System that stores data on plant genetic resources, pedigrees, and field and laboratory observations. The genealogy and selection history of selections and varieties of major food crops such as rice, maize and cassava can be extracted from this system. These data are available to cooperators around the world through the internet.

Some university and research institute libraries provide copies through the internet or e-mail of research articles requested by researchers in developing countries (for example, see IITA, 1999). Another example of innovative information exchange is the "grey literature" network of 28 institutions in nine Latin American countries coordinated by an IARC (CIAT). Abstracts and bibliographic references of student theses, annual reports, and working papers that have not been published but may be of keen regional interest are put on a compact disk and on the project's Web page for public use (CIAT, 1998).

FORCES AFFECTING FUTURE COLLABORATION

The need for future collaboration among agricultural researchers is fully as great if not greater than that faced by scientists in the 1960s. Absolute increases in food needs will be larger, and the constraints more substantial than were faced in the 1960-1980 period. For example, the dramatic production increases of the green revolution due to expansion of irrigated areas and of the use of chemical fertilizers will not be repeated. In fact, in some areas environmental constraints may dictate some reductions in the use of these two yield-enhancing inputs.

Similar constraints will limit the conversion of forests and grassland areas to farmland. On the contrary, it is likely that environmental and economic considerations will force the return of some farmed lands to their natural uncultivated states. Consequently, in the coming decades society will call upon science even more than in the past to help the world increase it's sustainable capacity to produce food.

Several forces driving world agriculture are having profound effects on the amount and nature of collaboration among agricultural researchers. *First*, the rates of production increase have declined recently over those achieved during green revolution days. For example, annual increases in the yields of cereals that were nearly 3.5% from 1970 to 1990 have dropped to slightly more than 1% since 1990. The 'easy' gains seem to have already been made, leaving the tougher ones for the future.

Second, there is a growing recognition that some gains in productivity achieved by the green revolution were not sustainable. Intensified monoculture farming systems tended to reduce biodiversity and to enhance soil degradation. Excessive use of pesticides and even fertilizers led to pollution of streams reservoirs, lakes, and even oceans. Irrigation in dry areas resulted in the buildup of salts to toxic levels if soil drainage were not adequate. Society will no longer tolerate such threats of environmental quality. Alternative means of sustainably increasing food production must be found.

Increasing concern about equity issues is the *third* force facing world agriculture. The question as to who benefits from agricultural progress is being asked, especially at it relates to the poor. Low income people in both urban and rural areas benefitted from the reduced food prices stemming from the green revolution. Even so, the numbers of low income people have not declined appreciably. Furthermore, families living in marginal areas befitted less than their counterparts in the better endowed areas where the green revolution technologies were most productive.

The *fourth* force affecting agriculture is the rapid expansion of basic research, especially that relating to biotechnology and genetic engineering. This development has great potential for helping solve some of agriculture's most serious problems. Biotechnology provides possibilities for raising basic yield levels, and for increasing genetic resistance to insects and diseases. It also shows potential for improving the nutritional qualities of food crops and animals, and of increasing the tolerance of crops to adverse climatic and soil constraints.

Biotechnology has great potential for helping to solve the hunger problems in the South. It could incorporate into the genetic framework of the crops and animals most of the technology needed to sustainably increase food production. Biotechnology could increase yields and improve nutritional quality and simultaneously reduce the inputs needed to produce the food.

The potential of biotechnology may have negative as well as positive implications. The risks of moving genes from one organism to another have not been well assessed. Such risks may not be limited to the species into which new genes are transferred, but to other species, including those growing in the wild. There is fear that such accidental gene transfer could result in unbridled damage, not only to humans but to other creatures as well. Such fears have already reduced the movement of genetic materials from one area to another, and will likely be more constraining to such movement in the future.

Unfortunately, biotechnology and related research have helped stimulate the *fifth* force that may well have the greatest significant for agricultural research generally and for cooperation in particularly. It deals with the shift in the ratio of support for public vs. private research. Most of the research that led to the green revolution, was supported by the public sector. Private institutions supported little of the research in developing countries, and less than half of that in industrialized countries.

This situation has changed dramatically in recent years. Economic constraints have forced significant reductions in public research funding in developing countries, and such support has barely held it's own in real terms in industrialized countries. Meanwhile, significant increases have occurred in private research, primarily in the North where agricultural research has shifted heavily toward biotechnology.

Much of the research is being supported by large transnational corporations that have become powerful players in most national economies. The number of such corporations has increased from about 700 in 1970 to nearly 54000 today (Brown, 1999). While such transnational companies encourage global economic collaboration, they also tend to emphasize the near-term profit motive that may not always be to the benefit of low income farmers of developing countries.

This increased interest of the private sector in agricultural research is welcome. However, the need for proprietary protection of biotechnology products, which is essential for profit-motivated companies, has grave implications for cooperation among participants in the research community. It has already had a chilling effect on the traditional free exchange of genetic materials that characterized the days of the green revolution. It has also raised questions as to the ownership of genetic materials in genetically engineered varieties, the genes of which have originated in the fields of low income farmers. It is apparent that biotechnology which has the potential of answering many of the problems of low income farmers may also have the potential of drastically reducing international research cooperation.

A *sixth* important force affecting agriculture is the growing number of environmentally and socially motivated non-governmental organizations (NGOs). Concern over the effects of unregulated and sometimes degrading utilization of natural resources, and over the welfare and lack of political power of low income people, particularly in the South, has stimulated the creation of tens of thousands of NGOs and many more informal associations (O'Connor, 1998). Some are defending the rights of low income rural people, while others are concerned primarily with environmental quality. Many are insisting on the participatory involvement of farmers and other rural people and organizations in the planning and implementation of agricultural research. Some emphatically oppose the growing power of multinational corporations, and others are equally opposed to genetically modified crops and animals.

NGOs already have had noted effects on collaborative research efforts. They often seek and obtain a seat at the table for the planning and implementing of agricultural research. More importantly, they insist that farmers and their organizations take part in these processes. Such participatory involvement is more and more becoming the norm, particularly in field-oriented research.

These six forces are among the factors that will determine the nature of future cooperation in international agricultural research. The roles which the public, private and NGO communities play will largely determine the nature of this cooperation as well as the future of sustainable agriculture (Harwood, 1998).

COLLABORATION IN THE FUTURE

The growing global interdependence will likely assure that collaborative research will continue in the future, However, it will be modified in response to the forces we have just discussed. If it is to be more effective, expansion in the network of collaborators must take place, both upstream and downstream. Basic researchers, many of whom are working in other than traditional agricultural research laboratories, will provide the tools needed to better understand the commodities and the systems upon which successful and sustainable agriculture depends. An example of such collaboration is that underway as the West African Rice Development Association (WARDA) tries to combine the qualities of Africa rices (*O. glaberrima*) with those of tropical Asian rices (*O. sativa*). Collaborators include a leading research institute in France (ORSTOM), two international research institutes (IRRI and CIAT), two U.S. universities (Cornell and Arkansas) and the University of Tokyo (WARDA, 1997).

Participatory research involving those who produce and eat the food as well as their local associations is showing dividends (Thrupp, 1997). Such participation helps the planners of research determine if they are working on the right problems. It also enhances the probability that the research findings will be accepted and used by the cultivators, and that farm products will be eaten by the consumers.

Collaborative research of the future will place greater emphasis on the sustainability of farming systems. The components of the systems, such as improved varieties, will still be one of the focal points of the research. But researchers will pay greater attention to the sustainability of the system into which the components fit. Alternatives to the use of pesticides to manage pests will receive high priority, as will efforts to recycle plant nutrients using combinations of organic and inorganic sources. Any innovation will be subject to evaluation, not only in terms of its long term effect on food production, but of its effect on factors such as biodiversity, and soil, water and air quality. Also, its effect on equity, and on human welfare (including human nutrition) must be considered. The involvement of farmers as well as NGOs in the research process will help assure that equity and environmental issues are addressed. The "Alternatives to Slash and Burn" project described earlier is a good example of a network where participatory research is being done.

The strategy of incorporating to the degree feasible improved technologies into the genetic makeup of plants and animals will be continued. The availability of plant varieties that will tolerate not only insects and diseases, but weeds, drought, and soil toxicities simplifies the cultivators decision making processes, and simultaneously reduces the production inputs needed.

The classical plant breeding format served humanity well during the green revolution, contributing greatly to the doubling of cereal grain harvests during the past 40 years. But rates of yield increase have declined, suggesting that the classical format must be complemented by other modern tools. The tools of biotechnology show great promise, not only in agriculture but in other fields such as health and environmental improvement. Researchers will use such tools, not just to increase the yields of plants and animals, but to gain a better understanding of the genetic makeup of these commodities, and of the pests that constrain agricultural production. Already research is underway to sequence the genome of the major cereals rice, maize and wheat (Riechmann *et al.*, 1999), and many attempts are being made to introduce into these and other plants genes known to have desirable functions.

POTENTIAL FOR SUCCESS

Research described at the 16th International Botanical Congress and reported briefly in a recent issue of *Science* magazine (Gura, 1999) illustrates the potential for cooperation in improving the nutritional quality of food crops. Genetic engineers have produced a rice strain that could combat vitamin A deficiency for 400 million people, and iron deficiency that affects some 3.7 billion people, particularly women. The research was done by scientists at the Swiss Federal Institute of Technology in Zurich, who worked with counterparts at the University of Freiburg in Germany, and at Hoffman-La Roche, a pharmaceutical corporation in Switzerland. The team genetically engineered a "golden rice" that contains beta-carotene, a precursor of vitamin A, along with increased levels of iron, and an enzyme that increases the absorption of iron in the human system. The cooperators are now turning to the International Rice Research Institute (IRRI) in the Philippines and its partners to cross breed the new rice with tropical Indica rices so that the billions of poor people in the tropics who consume rice can receive the nutritional benefits.

This success story is ideal in several respects. First, basic research institutions in the North over a period of 7 years focused on a food commodity consumed primarily by poor people in the South. They collaborated with others that provided genes from different species (daffodil, a bacterium and a fungus) which they introduced into the rice plant. They then turned to a quality institution located in the South to cross breed the new rice with other improved varieties. The collaborators included a private sector institution (Hoffman-LaRoche) along with three institutions from the public sector. In evaluating the Indica crosses, IRRI will likely collaborate with national agricultural and nutritional research centers and with farmers in developing countries.

Unfortunately, questions of intellectual property rights and competition among private sector corporations are making cooperation such as that just described very difficult. Furthermore, public support for biotechnology research is muted by fear of possible damaging effects of this process on the environment. Only in the private sector do we hear of significant increases in genetic engineering research. In any case, these developments are not encouraging the free exchange of products and research knowledge so essential for the future of agriculture.

There is some evidence of a growing recognition by some large corporations that enhancing environmental quality, including sustainable agriculture, is compatible with sound business practices. For example, three multinational corporations (General Motors, Monsanto and British Petroleum), have joined with the World Resources Institute in a "Safe climate, sound business initiative". In a recent report on their deliberations (WRI, 1998), they emphasize the importance of technological advances to meet both business and environmental goals. The critical role of basic research, especially that supported by the public sector, was also highlighted, along with the importance of genetic improvement and sustainable soil management. They stress the need for technological advancement in developing countries, and call for "redoubled technology cooperation ventures between and among developed and developing nations". This would include, of course, collaborative research ventures.

I am optimistic that the wisdom expressed by these four global institutions will prevail, and that some means will be found to encourage and support future international collaborative research endeavors. While governments and international public institutions may need to take the near-term leadership, they must be encouraged to do so by the private sector and NGOs, who in the long-term will interact most with the implementers of sustainable agricultural development. Basic research done at universities and research institutes in both the North and South will be coupled by innovative, joint ventures and networks that include private sector and NGO partners. The greatest beneficiaries of such partnerships will be small farmers and other low income families of the South.

REFERENCES

Altieri, M. (1996): *Agroecology: The Science of Sustainable Agriculture* (Boulder CO, Westview Press).

Brown, L.R. (1999): 'Off-the Chart Year', *Vital signs 1999*, eds. L.R. Brown, M. Renner and B. Halweil (Wash. D.C., Worldwatch Institute), pp. 15-39.

Castillo, G.T. (1998): 'Cultural Diversity through Genetic Diversity', *Biodiversity maintaining the balance: International Rice Research Institute Annual report 1997-98* (Manila Philippines, Int. Rice Res. Inst.), p. 31.

CGIAR (1998): *The CGIAR partnership: Working for Sustainable Food Security* (Wash. D.C., Consultative Group on International Research).

CGIAR (1999): *The Impact of Knowledge* (Wash. D.C., Consultative Group on International Agricultural Research).

Chang, T.T. (1998): 'What can Crop Scientists Contribute to Meeting Future Food Needs in the Twenty First Century?', *Proceedings of the 3rd Asian Crop Science Conference*, eds. Hsiu-Ying Lu, Jih-Min Sung and Ching Huei Kao (Taichung, Taiwan, Chinese Society of Agronomy).

CIAT (1998): 'Grey Literature for a Greener World', *Growing affinities, October, 1998* (Cali, Colombia, International Center for Tropical Agriculture), p. 3.

CIMMYT (1999): *A Sampling of CIMMYT Impacts, 1999* (Mexico D.F. Mexico, International Maize and Wheat Improvement Center).

Gura, T. (1999): 'New Genes Boost Rice Nutrients', *Science*, 285, pp. 994-995.

Harwood, R.R. (1998): 'Sustainability in Agricultural Systems in Transition – at what Cost?', Paper in *Workshop on Sustainability in Agricultural Systems in Transition* (Baltimore, MD, Cosponsors American Society of Agronomy; Soil Science Society of America, Crop Science Society of America, World Bank).

ICRAF (1998): 'Systemwide and Ecoregional Programs', *International Center for Research in Agroforestry Annual Report 1997* (Nairobi, Kenya, International Center for Research in Agroforestry), pp. 121-124.

IITA (1998): *Systemwide Program on Integrated Pest Management – Annual Report 1997-98* (Ibadan, Nigeria, International Institute of Tropical Agriculture).

IITA (1999): *International Institute of Tropical Agriculture Annual Report 1998* (Ibadan, Nigeria, International Institute of Tropical Agriculture).

NAS (1991): *Toward Sustainability: A Plan for Collaborative Research on Agriculture and Natural Resources Management* (Wash. D.C., National Academy Press).

O'Connor, J. (1998): *Natural Causes: Essays in Ecological Marxism* (New York, The Guilford Press).

Riechmann, J.L., Zhang, P., and Brown, P. (1999): 'Plant Genomics: the Next Green Revolution?' *Chemistry and Industry*, 21 June 1999, pp. 468-472.

Runyan, C. (1999): 'NGOs Proliferate Worldwide', *Vital Signs 1999*, eds. L.R. Brown, M. Renner and B. Halweil (Wash. D.C., Worldwatch Institute), pp. 144-145.

Sharma, S.B., Johansen, C., and Midha, S.K. (1998): *Nematode Pests in Rice-Wheat-Legume Cropping Systems – Proceedings of a Regional Training Course* (New Delhi, India, Rice-wheat Consortium for the Indo-Gangetic Plains) Rice-wheat Consortium paper series No. 4.

SPAAR (1998): *SPAAR: A Forum for Changing African Agriculture Through Research and Technology Transfer* (Wash. D.C., Special Program on African Agricultural Research, World Bank).

Tandon, P.N. (1998): 'Letter to the Editor', *Issues*, 15:6.

Thrupp, L.A. (1997): *New Partnerships in Sustainable Agriculture* (Wash. D.C., World Resources Institute).

WARDA (1997): *WARDA: Looking back into the Future* (Bouake, Ivory Coast, West African Rice Development Association).

WRI (1998): *Building a Safe Climate, Sound Business Future* (Wash. D.C., World Resources Institute).

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