ISSN 0081-4539

2003–04

THE STATE OF FOOD AND AGRICULTURE

AGRICULTURAL BIOTECHNOLOGY

Meeting the needs of the poor?

Cover photos: *(top left)* Vincent Martin (FAO-EMPRES); *(middle right)* FAO/12337/F. Botts

Copies of FAO publications can be requested from:

SALES AND MARKETING GROUP
Information Division
Food and Agriculture Organization of the United Nations
Viale delle Terme di Caracalla
00100 Rome, Italy

E-mail: publications-sales@fao.org
Fax: (+39) 06 57053360
Web site: http://www.fao.org

FAO Agriculture Series No. 35
ISSN 0081-4539

2003–04

THE STATE OF FOOD AND AGRICULTURE

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2004

Produced by the
Editorial Production and Design Group
Publishing Management Service
FAO

ISBN 92-5-105079-1

Contents

SECTION C: MAKING BIOTECHNOLOGY WORK FOR THE POOR

PART II
World and regional review: facts and figures

PART III
Statistical annex

SPECIAL CONTRIBUTIONS

BOXES

TABLES

FIGURES

MAP

Foreword

This edition of *The State of Food and Agriculture* explores the potential for agricultural biotechnology to address the needs of the world's poor and food-insecure. Agriculture continues to face serious challenges, including feeding an additional two billion people by the year 2030 from an increasingly fragile natural resource base. The effective transfer of existing technologies to poor rural communities and the development of new and safe biotechnologies can greatly enhance the prospects for sustainably improving agricultural productivity today and in the future. But technology alone cannot solve the problems of the poor and some aspects of biotechnology, particularly the socio-economic impacts and the food safety and environmental implications, need to be carefully assessed.

Developing biotechnology in ways that contribute to the sustainable development of agriculture, fisheries and forestry can help significantly in meeting the food and livelihood needs of a growing population. The study of genomics and molecular markers, for example, can facilitate breeding and conservation programmes and provide new tools in the fight against plant and animal diseases. It is clear from the survey of current and emerging applications of biotechnology in this report that biotechnology encompasses far more than genetic engineering. But it is the ability to move genes between unrelated species that gives genetic engineering its enormous power and elicits such profound concern. FAO recognizes the need for a balanced and comprehensive approach to biotechnological development, taking into consideration the opportunities and risks.

Biotechnology offers opportunities to increase the availability and variety of food, increasing overall agricultural productivity while reducing seasonal variations in food supplies. Through the introduction of pest-resistant and stress-tolerant crops, biotechnology could lower the risk of crop failure under difficult biological and climatic conditions. Furthermore, biotechnology could help reduce environmental damage caused by toxic agricultural chemicals. Following a first generation of genetically engineered crops, which aimed primarily at reducing production constraints and costs, a second generation now targets the bio-availability of nutrients and the nutritional quality of products. Examples are found in the production of varieties of rice and canola that contain appreciable amounts of beta-carotene. This precursor of vitamin A is in short supply in the diets of many, particularly in the developing world where it could help to alleviate or reduce chronic vitamin A deficiencies. Research is under way to raise levels of other vitamins, minerals and proteins in crops, such as potatoes and cassava.

This issue of *The State of Food and Agriculture* reviews the historical record of agricultural research in promoting economic growth and food security. The Green Revolution, which lifted millions of people out of poverty, came about through an international programme of public-sector agricultural research specifically aimed at creating and transferring technologies to the developing world as free public goods. The Gene Revolution, by contrast, is currently being driven primarily by the private sector, which naturally focuses on developing products for large commercial markets. This raises serious questions about the type of research that is being performed and the likelihood that the poor will benefit.

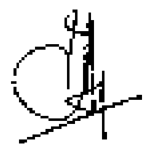
The emerging evidence on the economic impact of transgenic crops surveyed in this report suggests that resource-poor smallholders in developing countries can benefit in terms of both enhanced incomes and reduced exposure to toxic agricultural chemicals. But so far only a few farmers in a few developing countries are reaping these benefits. Neither the private nor the public sector has invested significantly in new genetic technologies for the so-called "orphan crops" such as cowpea, millet, sorghum and tef that are critical for the food supply and livelihoods of the world's poorest people. Other barriers that prevent the poor from accessing and fully benefiting from modern biotechnology include inadequate regulatory procedures, complex intellectual property issues, poorly functioning markets and seed delivery systems, and weak domestic plant breeding capacity.

FAO is well aware of the potential environmental and food safety risks posed by certain aspects of biotechnology, particularly genetically modified organisms (GMOs). This issue of *The State of Food and Agriculture* reviews the latest scientific evidence contained in several independent, authoritative reports from around the world. Reports from the International Council for Science, the Nuffield Council on Bioethics, the United Kingdom GM Science Review Panel and numerous national academies of science form the basis of this review. The scientific evidence concerning the environmental and health impacts of genetic engineering is still emerging. Scientists generally agree that the transgenic crops currently being grown and the foods derived from them are safe to eat, although little is known about their long-term effects. There is less scientific agreement on the environmental impacts of transgenic crops. Scientists generally agree on the nature of the potential environmental risks, although they differ regarding their likelihood and consequences. There is strong consensus among scientists concerning the need for a case-by-case evaluation that considers the potential benefits and risks of individual GMOs compared with alternative technologies. The legitimate concerns for the safety of each transgenic product must be addressed prior to its release. Careful monitoring of the post-release effects of these products is essential.

With this report, I wish to take the opportunity to assure the international community that, through holistic and multidisciplinary scientific approaches of risk evaluation, including risk assessment, risk management and risk communication, FAO will continue to address all issues of concern to its constituents regarding biotechnology and its effects on human, plant and animal health. In view of the importance of harmonizing regulations related to the testing and releasing of GMOs, FAO will continue, at the national, subregional and regional levels, to strengthen its normative and advisory work, in coordination and cooperation with other international organizations. I am particularly pleased to note that the Codex Alimentarius Commission, for which FAO and the World Health Organization (WHO) jointly provide the secretariat, has recently adopted landmark agreements on principles for the evaluation of food derived from modern biotechnologies and on guidelines for the conduct of food safety assessment of foods derived from recombinant-DNA plants as well as from foods produced using recombinant-DNA micro-organisms. These principles and guidelines, when properly implemented, will enhance capacities to assess the risks of transferring toxins from one life form to another, of creating new toxins or of transferring allergenic compounds from one species to another.

FAO will continue to provide member countries with objective, science-based information and analysis regarding biotechnology and its applications in crops, livestock, fisheries and forestry. FAO technical cooperation will encompass advising Member Governments on regulatory issues including harmonization at regional and international levels, offering legal advice for the establishment of any required regulatory bodies, improving national capacity for risk assessment, mobilizing donor funding and cooperating with other relevant organizations.

I therefore appeal to the international community to join FAO in its continuing efforts towards alleviating poverty and hunger through the promotion of agricultural development, the improvement of nutrition and the pursuit of food security throughout the world. With your help, success is at the end of our efforts, perseverance and commitment.



Jacques Diouf
FAO DIRECTOR-GENERAL

Preface

The State of Food and Agriculture 2003–04 has a new look and a new format that we hope you find attractive, informative and stimulating. Beginning with this issue, the report focuses on one important theme in agricultural and economic development each year, providing an in-depth analysis of its socio-economic implications and exploring policy options better to meet the needs of poor people in developing countries. We expect these thematic reports to make a significant contribution to the global debate on agricultural and economic development among policy-makers, the research community, development professionals and civil society. The theme this year is "Agricultural biotechnology: meeting the needs of the poor?" In subsequent issues, it is planned to address international trade, domestic agricultural markets and related global issues that influence the livelihoods and food security of the poor.

This new edition of the *State of Food and Agriculture* continues our tradition of providing a succinct overview of the current food and agriculture situation at the world and regional levels, including the latest estimates of the number of undernourished people; commodity production, trade and price trends; and agricultural investment, support and external assistance. The print version of this world and regional overview is supplemented periodically throughout the year with more comprehensive and timely regional reports. These regional reports can be accessed from our Web site at www.fao.org/es/esa. In addition, we introduce a new series of national agricultural and food security indicators with this year's report. These indicators will evolve over the coming years to provide a tool for monitoring the state of food and agriculture across countries and over time.

The State of Food and Agriculture 2003–04 is the first to be produced under a new management team comprising Prabhu Pingali, Director of the Agricultural and Development Economics Division (ESA), Randy Stringer, Chief of the Comparative Agricultural Development Service, and Terri Raney, Editor and Senior Economist for *The State of Food and Agriculture*. The Director-General of FAO, Jacques Diouf, and the Assistant Director-General of the Economic and Social Department, Hartwig de Haen, were instrumental in this effort to revitalize the report. The team is also grateful for the advice and support provided by the report's External Advisory Board: Walter P. Falcon (Chair United States), Bina Agarwal (India), Kym Anderson (Australia), Simeon Ehui (Côte d'Ivoire), Franz Heidhues (Germany) and Eugenia Muchnik (Chile).

The *State of Food and Agriculture* team is particularly keen to hear your reactions to this report and your suggestions for future issues. We look forward to hearing from you at SOFA@fao.org.

Terri Raney
Editor
The State of Food and Agriculture

Acknowledgements

The State of Food and Agriculture 2003–04 was prepared by a team from the Comparative Agricultural Development Service, led by Terri Raney. Team members included Jakob Skoet, André Croppenstedt, Annelies Deuss, Fulvia Fiorenzi, Slobodanka Teodosijevic and Stefano Trento. Secretarial support was provided by Stella Di Lorenzo and Paola Di Santo. General supervision was provided by Randy Stringer, Chief, Comparative Agricultural Development Service, and Prabhu Pingali, Director, Agricultural and Development Economics Division.

Part I, "Agricultural biotechnology: meeting the needs of the poor?", was written by Terri Raney with contributions from many FAO technical units and international experts. Background research for Part I was conducted by Joel Cohen, José Falck-Zepeda, Thomas Hoban, John Komen, Anwar Naseem, Prabhu Pingali, Carl Pray, Terri Raney and Greg Traxler. Many of these papers have been published in the ESA Working Paper series and can be found at www.fao.org/es/esa. The FAO Inter-Departmental Working Group on Biotechnology provided additional background material, draft texts, reviews and financial support. The report benefited greatly from the support of the Working Group, in particular James Dargie, Chair. Full bibliographic references are supplied at the end of the report. In addition to the lead author, the main contributors to the chapters were as follows:

Chapter 2 (What is agricultural biotechnology?). Draft texts were contributed by Jonathan Robinson, James Dargie and Irene Hoffman. Additional material was taken from the background papers for the FAO Electronic Forum on Biotechnology in Food and Agriculture prepared by John Ruane. Additional inputs were provided by Devin Bartley, Elcio Guimarães, Keith Hammond (retired), Hoan Le, Prakash Shetty and Pierre Sigaud. The following international experts generously contributed summaries of their ongoing biotechnology research: Mike Gale of the John Innes Centre on synteny; Miftahudin, Miguel Rodriguez Milla, Kathleen Ross and J. Perry Gustafson variously of Bogor Agricultural University, the University of Missouri and the United States Department of Agriculture on aluminium tolerance; and Tom Hash of the International Crops Research Institute for the Semi-Arid Tropics on marker-assisted selection for downy mildew resistance in pearl millet.

Chapter 3 (Green to Gene). Background papers were prepared by Prabhu Pingali and Terri Raney, Carl Pray and Anwar Naseem, and Greg Traxler. Norman Borlaug and M.S. Swaminathan wrote special contributions for this chapter.

Chapter 4 (Economic impacts). Greg Traxler prepared a background paper and additional inputs were contributed by the following international experts: Kym Anderson, Richard Bennett, Liborio Cabanilla, Matin Qaim and Eric Tollens.

Chapter 5 (Concerns). Christina Devorshak, Daniele Manzella and Andrew Speedy contributed texts and background material. Alessandro Pellegrineschi and David Hoisington of the International Maize and Wheat Improvement Center wrote the box on the "clean gene" transformation technique and Allison Snow of Ohio State University wrote the box on the ecological assessment of transgenic crops.

Chapter 6 (Public attitudes). Thomas Hoban prepared a background paper on public opinion research and Janice Albert contributed the text on labelling.

Chapter 7 (Research policy). Background papers were prepared by Carl Pray and Anwar Naseem, Prabhu Pingali and Terri Raney, and Greg Traxler.

Chapter 8 (Capacity building). Background papers were prepared by José Falck-Zepeda, Joel Cohen and John Komen, and by Fulvia Fiorenzi.

Chapter 8 (Capacity building). Kakoli Ghosh contributed draft text with additional inputs from Andrea Sonnino.

Chapter 9 (Conclusions). Randy Stringer prepared the draft text for this chapter.

Part II, "World and regional review: facts and figures", was prepared by Annelies Deuss and Jakob Skoet.

Part III, "Statistical annex", was prepared by André Croppenstedt, Annelies Deuss and Randy Stringer.

The team is particularly grateful to the *State of Food and Agriculture* External Advisory Board, comprising Walter Falcon (Chair), Bina Agarwal, Kym Anderson, Simeon Ehui, Franz Heidhues and Eugenia Muchnik, who provided valuable guidance on the scope and focus of the report. External reviews by Hermann Waibel, Diemuth Pemsl and Sarah Hearne are gratefully acknowledged.

The report benefited from the work of the editors, designers and layout artists of the FAO Publishing Management Service.

Glossary

AATF	African Agricultural Technology Foundation
AEBC	United Kingdom Agriculture and Environment Biotechnology Commission
AGERI	Agricultural Genetic Engineering Research Institute – Egypt
AI	artificial insemination
AIA	Advance Informed Agreement
Bt	*Bacillus thuringiensis*
CAAS	Chinese Academy of Agricultural Sciences
CAC	Codex Alimentarius Commission
CAMBIA	Center for the Application of Molecular Biology to International Agriculture
CBD	Convention on Biological Diversity
CGIAR	Consultative Group on International Agricultural Research
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
COPERSUCAR	Cooperative of Cane, Sugar and Ethanol Producers of the State of São Paulo, Brazil
D&PL	Delta and Pine Land Company
DEA	data envelopment analysis
DFID	Department for International Development – United Kingdom
DNA	deoxyribonucleic acid
EGR	evergreen revolution
ELISA	enzyme-linked immunosorbent assay
Embrapa	Brazilian Agricultural Research Corporation
GAO	United States Government Accounting Office
GDP	gross domestic product
GEF	Global Environment Facility

GEO	genetically engineered organism
GIEWS	Global Information and Early Warning System on Food and Agriculture
GM	genetically modified
GMO	genetically modified organism
GNP	gross national product
GREP	Global Rinderpest Eradication Programme
HT	herbicide tolerant
IAEA	International Atomic Energy Agency
IARC	International Agricultural Research Centre
IBS	ISNAR Biotechnology Service
ICGEB	International Centre for Genetic Engineering and Biotechnology
ICCO	International Cocoa Organization
ICO	International Coffee Organization
ICPM	Interim Commission on Phytosanitary Measures
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICSU	International Council for Science
IFPRI	International Food Policy Research Unit
IPPC	International Plant Protection Convention
IPR	intellectual property rights
IRRI	International Rice Research Institute
ISA	International Sugar Agreement
ISAAA	International Service for the Acquisition of Agri-biotech Applications
ISNAR	International Service for National Agricultural Research
ISPM	international standards for phytosanitary measures
LMO	living modified organism
MAS	marker-assisted selection
MOET	multiple ovulation followed by embryo transfer
MTA	material transfer agreement

NARS	national agricultural research systems
NAS	National Academy of Sciences
NGO	non-governmental organization
NPB	National Programme for Biotechnology
NRC	National Research Council – United States
NTSBD	National Taskforce for Sustainable Biotechnological Development
OECD	Organisation for Economic Co-operation and Development
OIE	World Organisation for Animal Health (formerly International Office of Epizootics)
PARC	Pan African Rinderpest Eradication Campaign
PCR	polymerase chain reaction
PPP	purchasing power parity
R&D	research and development
RFLP	restriction fragment length polymorphism
RNA	ribonucleic acid
RR	RoundupReady®
SIDA	Swedish International Development Cooperation Agency
SPS	Sanitary and Phytosanitary Measures
TBT	Technical Barriers to Trade
TFP	total factor productivity
TRIPS	Trade-Related Aspects of Intellectual Property Rights
UNDP	United Nations Development Programme
UNIDO	United Nations Industrial Development Organization
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WFP	Wold Food Programme
WHO	World Health Organization
WTO	World Trade Organization

Explanatory note

The statistical information in this issue of *The State of Food and Agriculture* has been prepared from information available to FAO up to November 2003.

Symbols

The following symbols are used:

– = none or negligible (in tables)

... = not available (in tables)

$ = US dollars

Dates and units

The following forms are used to denote years or groups of years:

2001/02 = a crop, marketing or fiscal year running from one calendar year to the next

2001–02 = the average for the two calendar years

Unless otherwise indicated, the metric system is used in this publication.

"Billion" = 1 000 million.

Statistics

Figures in statistical tables may not add up because of rounding. Annual changes and rates of change have been calculated from unrounded figures.

Production indices

The FAO indices of agricultural production show the relative level of the aggregate volume of agricultural production for each year in comparison with the base period 1989–91. They are based on the sum of price-weighted quantities of different agricultural commodities after the quantities used as seed and feed (similarly weighted) have been deducted. The resulting aggregate therefore represents disposable production for any use except seed and feed.

All the indices, whether at the country, regional or world level, are calculated by the Laspeyres formula. Production quantities of each commodity are weighted by 1989–91 average international commodity prices and summed for each year. To obtain the index, the aggregate for a given year is divided by the average aggregate for the base period 1989–91.

Trade indices

The indices of trade in agricultural products are also based on the base period 1989–91. They include all the commodities and countries shown in the *FAO Trade Yearbook*. Indices of total food products include those edible products generally classified as "food".

All indices represent changes in current values of exports (free on board [f.o.b.]), and imports (cost, insurance, freight [c.i.f.]), expressed in US dollars. When countries report imports valued at f.o.b., these are adjusted to approximate c.i.f. values.

Volumes and unit value indices represent the changes in the price-weighted sum of quantities and of the quantity-weighted unit values of products traded between countries. The weights are, respectively, the price and quantity averages of 1989-91 which is the base reference period used for all the index number series currently computed by FAO. The Laspeyres formula is used to construct the index numbers.

Part I

AGRICULTURAL BIOTECHNOLOGY

Meeting the needs of the poor?

Part I

Section **A**: Framing the debate

1. Can biotechnology meet the needs of the poor?

Introduction and overview

Biotechnology in food and agriculture, particularly genetic engineering, has become the focus of a "global war of rhetoric" (Stone, 2002). Supporters hail genetic engineering as essential to addressing food insecurity and malnutrition in developing countries and accuse opponents of "crimes against humanity" for delaying the regulatory approval of potentially life-saving innovations (Potrykus, 2003). Opponents claim that genetic engineering will wreak environmental catastrophe, worsen poverty and hunger, and lead to a corporate takeover of traditional agriculture and the global food supply. They accuse biotechnology supporters of "fooling the world" (Five Year Freeze, 2002). This issue of *The State of Food and Agriculture* surveys the current state of scientific and economic evidence regarding the potential of agricultural biotechnology, particularly genetic engineering, to meet the needs of the poor.

Agriculture in the twenty-first century is facing unprecedented challenges. An additional 2 billion people will have to be fed over the next 30 years from an increasingly fragile natural resource base. More than 842 million people are chronically hungry, most of them in rural areas of poor countries, and billions suffer from micronutrient deficiencies, an insidious form of malnutrition caused by the poor quality of, and lack of diversity in, their habitual diet. The Green Revolution taught us that technological innovation – higher-yielding seeds and the inputs required to make them grow – can bring enormous benefits to poor people through enhanced efficiency, higher incomes and lower food prices. This virtuous cycle of rising productivity, improving living standards and sustainable economic growth has lifted millions of people out of poverty (Evenson and Gollin, 2003). But many remain trapped in subsistence agriculture. Can the Gene Revolution reach those left behind?

At the same time, a rapidly urbanizing global population is demanding a wider range of quality attributes from agriculture, not just of the products themselves but of the methods used in their production. The agriculture sector will need to respond in ways beyond the traditional focus on higher yields, addressing the protection of environmental common goods, consumer concerns for food safety and quality, and the enhancement of rural livelihoods both in the South and in the North. Is the rhetoric of war deafening us to a more reasoned debate regarding the hazards and opportunities posed by biotechnology?

There is clear promise that biotechnology (Box 1) can contribute to meeting these challenges. Biotechnology can overcome production constraints that are more difficult or intractable with conventional breeding. It can speed up conventional breeding programmes and provide farmers with disease-free planting materials. It can create crops that resist pests and diseases,

BOX 1
Scope of the report

Agricultural biotechnology encompasses a range of research tools scientists use to understand and manipulate the genetic make-up of organisms for use in agriculture: crops, livestock, forestry and fisheries. Biotechnology is much broader than genetic engineering, including also genomics and bioinformatics, marker-assisted selection, micropropagation, tissue culture, cloning, artificial insemination, embryo transfer and other technologies. However, genetic engineering, particularly in the crop sector, is the area in which biotechnology is most directly affecting agriculture in developing countries and in which the most pressing public concerns and policy issues have arisen. It is also an area in which a body of economic evidence regarding the impact of biotechnology on the poor is beginning to emerge. Therefore, although this report touches on the full range of agricultural biotechnology tools and applications, particularly in Chapter 2, the focus is on transgenic crops and their impact on poor people in poor countries.

Many of the challenges to securing the benefits of transgenic crops for the poor will be equally or more difficult for other biotechnology applications in livestock, fisheries and forestry. For more information on FAO's programme of work on agricultural biotechnology, see the FAO biotechnology Web site at http://www.fao.org/biotech/index.asp?lang=en.

replacing toxic chemicals that harm the environment and human health, and it can provide diagnostic tools and vaccines that help control devastating animal diseases. It can improve the nutritional quality of staple foods such as rice and cassava and create new products for health and industrial uses.

But biotechnology is not a panacea. It cannot overcome the gaps in infrastructure, markets, breeding capacity, input delivery systems and extension services that hinder all efforts to promote agricultural growth in poor, remote areas. Some of these challenges may be more difficult for biotechnology than for other agricultural technologies, but others may be less difficult. Technologies that are embodied in a seed, such as transgenic insect resistance, may be easier for small-scale, resource-poor farmers to use than more complicated crop technologies that require other inputs or complex management strategies. On the other hand, some biotechnology packages, particularly in the livestock and fisheries areas, require a certain institutional and managerial environment to function properly and thus may not be effective for resource-poor smallholders.

The safety and regulatory concerns associated with transgenic crops constitute a major hurdle for developing countries, because many lack the regulatory frameworks and technical capacity necessary to evaluate these crops and the conflicting claims surrounding them. Although the international scientific community has determined that foods derived from the transgenic crops currently on the market are safe to eat, it also acknowledges that some of the emerging transformations involving multiple transgenes may require additional food-safety risk-analysis procedures. There is less scientific consensus on the environmental hazards associated with transgenic crops, although there is general agreement that these products should be evaluated against the hazards associated with conventional agriculture. There is also wide consensus that transgenic crops should be evaluated on a case-by-case basis, as is the case with pharmaceuticals, taking into consideration the specific crop, trait and agro-ecological system. Because very few transgenic crops have been evaluated for their ecological impacts in tropical regions, a major research effort is required in this area.

Public- and private-sector transgenic crop research and development are being carried out on more than 40 crops worldwide and dozens of innovations are being studied, but there is clear evidence that the problems of the poor are being neglected. Barring a few initiatives here and there, there are no major public- or private-sector programmes to tackle the critical problems of the poor or targeting crops and animals that they rely on. Concerted international efforts are required to ensure that the technology needs of the poor are addressed and that barriers to access are overcome.

Capacity building for agricultural research and regulatory issues related to biotechnology should be a priority for the international community. FAO has proposed a major new programme to ensure that developing countries have the knowledge and skills necessary to make their own decisions about the use of biotechnology.

Key lessons from the report

Biotechnology – including genetic engineering – can benefit the poor when appropriate innovations are developed and when poor farmers in poor countries have access to them on profitable terms. Thus far, these conditions are only being met in a handful of developing countries.

Biotechnology should form part of an integrated and comprehensive agricultural research and development programme that gives priority to the problems of the poor. Biotechnology can complement but not substitute for research in other areas such as plant breeding, integrated pest and nutrient management, and livestock breeding, feeding and disease management systems.

The public sector – developing and developed countries, donors and the international research centres – should direct more resources to agricultural research, including biotechnology. Public-sector research is necessary to address the public goods that the private sector would naturally overlook and to provide competition in technology markets.

Governments should provide incentives, institutions and an enabling environment for public- and private-sector agricultural biotechnology research, development and deployment. Public–private partnerships and other innovative strategies to mobilize research and technology delivery for the poor should be encouraged.

Regulatory procedures should be strengthened and rationalized to ensure that the environment and public health are protected and that the process is transparent, predictable and science-based. Appropriate regulation is essential to command the trust of both consumers and producers, but duplicative or obstructionist regulation is costly and should be avoided.

Summary of the report

Chapter 2 explores the frontiers of agricultural biotechnology and places it in the broader context of the production, conservation and management goals that researchers are addressing. Most of the controversies surrounding biotechnology focus on transgenic crops, but these innovations represent only a tiny fraction of the technical possibilities offered by biotechnology in crops, livestock, forestry and fisheries. Genetic engineering is both a more precise extension of breeding tools that have been used for decades and a radical departure from conventional methods. It is the ability of genetic engineering to move genes across species barriers that gives it its tremendous power and that makes it so controversial.

Chapter 3 recalls the role of public-sector research at the national and international levels in generating the technologies that produced the Green Revolution. By contrast, most transgenic crop research is being performed by the private transnational sector. This has important implications for the kind of research that is being performed and the products that are being developed. Research trends and commercialization data confirm that the crops and traits of concern to the poor are being neglected. Six countries (Argentina, Brazil, Canada, China, South Africa and the United States of America), four crops (maize, soybean, canola/rapeseed and cotton) and two traits (insect resistance and herbicide tolerance) accounted for 99 percent of the global area planted in transgenic crops in 2003. These same crops and traits are the subject of most of the transgenic crop research under way in both developed and developing countries and in the public and private sectors. One of the key constraints developing countries face in adopting and adapting biotechnology innovations developed elsewhere is their own lack of national agricultural research capacity.

Chapter 4 reviews the evidence to date regarding the socio-economic impacts of transgenic crop adoption, particularly in developing countries. With the exception of those in China, all transgenic crops commercialized to date have been developed and distributed by private companies. Nevertheless, some of these crops, especially insect-resistant cotton, are yielding significant economic gains to small farmers as well as important social and environmental benefits through the changing use of agricultural chemicals. The evidence so far suggests that small farmers are just as likely as large farmers to benefit from the adoption of transgenic cotton. The evidence also suggests that, despite fears of corporate control of the sector, farmers and consumers so far are reaping a larger share of the economic benefits of transgenic crops than the companies that develop and market them. It must be considered, however, that this evidence is based on only two or three years of data for a relatively small number of farmers in just a few countries. These short-term gains may not be sustained as larger numbers of farmers adopt the technologies. Time and more carefully designed studies are required to determine what the level and distribution of benefits from transgenic crops will be.

Chapter 5 reviews the scientific concerns and evidence associated with transgenic crops and summarizes the international scientific consensus where it exists. Scientists have determined that the transgenic products currently on the market are safe to eat, although they recommend ongoing monitoring and concur that newer, more complex products may need additional food safety procedures. The potential environmental impacts of transgenic crops provoke greater disagreement among scientists. They generally agree on the types of hazard that exist, but they disagree on their likelihood and severity. Thus far, none of the major environmental hazards potentially associated with transgenic crops has developed in the field. Scientists agree that transgenic crops must be evaluated on a case-by-case basis taking into consideration the crop, the trait and the agro-ecosystem in which it is to be released. Scientists also agree that regulation should be science-based, but that judgement and dialogue are essential elements in any science-based regulatory framework. International harmonization through the Codex Alimentarius Commission (CAC) or the International Plant Protection Convention (IPPC), for example, can help ease international tensions in this area. Developing countries must enhance their national capacity to regulate these crops and comply with their national and international obligations.

Chapter 6 reviews global public opinion research on the use of biotechnology in food and agriculture. Whatever scientific or regulatory consensus emerges, genetic engineering in food and agriculture cannot succeed unless the public is convinced of its safety and usefulness. Views on these subjects vary widely both within and across countries, but a careful examination of the internationally comparable survey data reveals that people in all countries take a nuanced view of biotechnology, differentiating among technologies and applications according to their perceived usefulness and acceptability. Very few people take a doctrinaire position for or against all biotechnology. Labelling has been proposed as a way to bridge differences of opinion on the acceptability of transgenic foods by allowing the individual consumer to choose. Others argue that labelling is appropriate only if the product – not just the process used to produce it – differs from its conventional counterpart. Member governments of the CAC are debating the role of labelling for transgenic foods.

Chapter 7 looks at the kind of agricultural biotechnology research that is needed to address the needs of the poor, particularly poor farmers in poor countries. This includes research on the crops that provide the bulk of their food supply and livelihoods: rice and wheat, of course, but also a variety of so-called "orphan crops" such as sorghum, pearl millet, pigeon pea, chickpea and groundnut that are largely neglected in conventional or biotechnology research programmes. Traits of particular interest to the poor include resistance to production stresses such as drought, salinity, disease and pests, as well as nutritional enhancement. This chapter also explores a range of institutional options and incentives that could help promote public- and private-sector research on the problems of the poor.

Chapter 8 addresses the capacity-building needs of developing countries and countries with economies in transition. All countries need strong and dynamic capacity at the technical, institutional and management levels for the successful and sustainable application of biotechnology in food and agriculture. Several international initiatives to build capacity are reviewed, but a great deal more needs to be done if all countries are to be empowered to make their own decisions about these technologies for the benefit of their own people.

Chapter 9 draws together the essential conclusions from the report and recommends specific steps to ensure that biotechnology helps meet the needs of the poor.

2. What is agricultural biotechnology?

Broadly speaking, biotechnology is any technique that uses living organisms or substances from these organisms to make or modify a product for a practical purpose (Box 2). Biotechnology can be applied to all classes of organism – from viruses and bacteria to plants and animals – and it is becoming a major feature of modern medicine, agriculture and industry. Modern agricultural biotechnology includes a range of tools that scientists employ to understand and manipulate the genetic make-up of organisms for use in the production or processing of agricultural products.

Some applications of biotechnology, such as fermentation and brewing, have been used for millennia. Other applications are newer but also well established. For example, micro-organisms have been used for decades as living factories for the production of life-saving antibiotics including penicillin, from the fungus *Penicillium*, and streptomycin from the bacterium *Streptomyces*. Modern detergents rely on enzymes produced via biotechnology, hard cheese production largely relies on rennet produced by biotech yeast and human insulin for diabetics is now produced using biotechnology.

BOX 2
Defining agricultural biotechnology

The Convention on Biological Diversity (CBD) defines biotechnology as: "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products for specific use" (Secretariat of the Convention on Biological Diversity, 1992). This definition includes medical and industrial applications as well as many of the tools and techniques that are commonplace in agriculture and food production.

The Cartagena Protocol on Biosafety defines "modern biotechnology" more narrowly as the application of:

(a) *In vitro nucleic acid techniques, including recombinant deoxyribonucleic acid (DNA) and direct injection of nucleic acid into cells or organelles, or*

(b) *Fusion of cells beyond the taxonomic family, that overcome natural physiological reproductive or recombination barriers and that are not techniques used in traditional breeding and selection.*

(Secretariat of the Convention on Biological Diversity, 2000)

The FAO *Glossary of biotechnology* defines biotechnology broadly as in the CBD and narrowly as "a range of different molecular technologies such as gene manipulation and gene transfer, DNA typing and cloning of plants and animals" (FAO, 2001a).

Recombinant DNA techniques, also known as genetic engineering or (more familiarly but less accurately) genetic modification, refer to the modification of an organism's genetic make-up using transgenesis, in which DNA from one organism or cell (the transgene) is transferred to another without sexual reproduction. Genetically modified organisms (GMOs) are modified by the application of transgenesis or recombinant DNA technology, in which a transgene is incorporated into the host genome or a gene in the host is modified to change its level of expression. The terms "GMO", "transgenic organism" and "genetically engineered organism (GEO)" are often used interchangeably although they are not technically identical. For the purposes of this report they are used as synonyms.

Biotechnology is being used to address problems in all areas of agricultural production and processing. This includes plant breeding to raise and stabilize yields; to improve resistance to pests, diseases and abiotic stresses such as drought and cold; and to enhance the nutritional content of foods. Biotechnology is being used to develop low-cost disease-free planting materials for crops such as cassava, banana and potato and is creating new tools for the diagnosis and treatment of plant and animal diseases and for the measurement and conservation of genetic resources. Biotechnology is being used to speed up breeding programmes for plants, livestock and fish and to extend the range of traits that can be addressed. Animal feeds and feeding practices are being changed by biotechnology to improve animal nutrition and to reduce environmental waste. Biotechnology is used in disease diagnostics and for the production of vaccines against animal diseases.

Clearly, biotechnology is more than genetic engineering. Indeed, some of the least controversial aspects of agricultural biotechnology are potentially the most powerful and the most beneficial for the poor. Genomics, for example, is revolutionizing our understanding of the ways genes, cells, organisms and ecosystems function and is opening new horizons for marker-assisted breeding and genetic resource management. At the same time, genetic engineering is a very powerful tool whose role should be carefully evaluated. It is important to understand how biotechnology – particularly genetic engineering – complements and extends other approaches if sensible decisions are to be made about its use.

This chapter provides a brief description of current and emerging uses of biotechnology in crops, livestock, fisheries and forestry with a view to understanding the technologies themselves and the ways they complement and extend other approaches. It should be emphasized that the tools of biotechnology are just that: tools, not ends in themselves. As with any tool, they must be assessed within the context in which they are being used.

Understanding, characterizing and managing genetic resources

Farmers and pastoralists have manipulated the genetic make-up of plants and animals since agriculture began more than 10 000 years ago. Farmers managed the process of domestication over millennia, through many cycles of selection of the best adapted individuals. This exploitation of the natural variation in biological organisms has given us the crops, plantation trees, farm animals and farmed fish of today, which often differ radically from their early ancestors (see Table 1).

The aim of modern breeders is the same as that of early farmers – to produce superior crops or animals. Conventional breeding, relying on the application of classic genetic principles based on the phenotype or physical characteristics of the organism concerned, has been very successful in introducing desirable traits into crop cultivars or livestock breeds from domesticated or wild relatives or mutants (Box 3). In a conventional cross, whereby each parent donates half the genetic make-up of the progeny, undesirable traits may be passed on along with the desirable ones, and these undesirable traits may then have to be eliminated through successive generations of breeding. With each generation, the progeny must be tested for its growth characteristics as well as its nutritional and processing traits. Many generations may be required before the desired combination of traits is found, and time lags may be very long, especially for perennial crops such as trees and some species of livestock. Such phenotype-based selection is thus a slow, demanding process and is expensive in terms of both time and money. Biotechnology can make the application of conventional breeding methods more efficient.

Genomics

The most significant breakthroughs in agricultural biotechnology are coming from research into the structure of genomes and the genetic mechanisms behind economically important traits (Box 4). The rapidly progressing discipline of genomics is providing information on the identity, location, impact and function of genes affecting such traits – knowledge that

TABLE 1
An agricultural technology timeline

Technology	Era	Genetic interventions
Traditional	About 10 000 years BC	Civilizations harvested from natural biological diversity, domesticated crops and animals, began to select plant materials for propagation and animals for breeding
	About 3 000 years BC	Beer brewing, cheese making and wine fermentation
Conventional	Late nineteenth century	Identification of principles of inheritance by Gregor Mendel in 1865, laying the foundation for classical breeding methods
	1930s	Development of commercial hybrid crops
	1940s to 1960s	Use of mutagenesis, tissue culture, plant regeneration. Discovery of transformation and transduction. Discovery by Watson and Crick of the structure of DNA in 1953. Identification of genes that detach and move (transposons)
Modern	1970s	Advent of gene transfer through recombinant DNA techniques. Use of embryo rescue and protoplast fusion in plant breeding and artificial insemination in animal reproduction
	1980s	Insulin as first commercial product from gene transfer. Tissue culture for mass propagation in plants and embryo transfer in animal production
	1990s	Extensive genetic fingerprinting of a wide range of organisms. First field trials of genetically engineered plant varieties in 1990 followed by the first commercial release in 1992. Genetically engineered vaccines and hormones and cloning of animals
	2000s	Bioinformatics, genomics, proteomics, metabolomics

Source: Adapted from van der Walt (2000) and FAO (2002a).

BOX 3
Induced mutation-assisted breeding

Spontaneous mutations are the "natural" motor of evolution, and the resource into which breeders tap to domesticate crops and to "create" better varieties. Without mutations, there would be no rice, or maize or any other crop.

Starting in the 1970s, the International Atomic Energy Agency (IAEA) and FAO sponsored research on mutation induction to enhance genetic improvement of food and industrial crops for breeding new improved varieties. Induced mutations are brought about by treating plant parts with chemical or physical mutagens and then selecting for desirable changes – in effect, to mimic spontaneous mutations and artificially broaden genetic diversity. The precise nature of the mutations induced has generally not been a concern irrespective of whether the mutant lines were used directly or as sources of new variation in cross-breeding programmes.

Induced mutation to assist breeding has resulted in the introduction of new varieties of many crops such as rice, wheat, barley, apples, citrus, sugar cane and banana (the FAO/IAEA Mutant Varieties Database lists more than 2 300 officially released varieties[1]). The application of mutation induction to crop breeding has translated into a tremendous economic impact on agriculture and food production that is currently valued in billions of US dollars and millions of hectares of cultivated land. Recently, mutation techniques have undergone a renaissance, expanding beyond their direct use in breeding into novel applications such as gene discovery and reverse genetics.

[1] Available at http://www-infocris.iaea.org/MVD/.

BOX 4
DNA from the beginning

All living things are made up of cells that are programmed by genetic material called deoxyribonucleic acid (DNA). Only a small fraction of the DNA chain actually makes up genes, which in turn code for proteins, and the remaining share of the DNA represents non-coding sequences whose role is not yet clearly understood. The genetic material is organized into pairs of chromosomes. For example, there are five chromosome pairs in the much-studied mustard species *Arabidopsis thaliana*. An organism's entire set of chromosomes is called the genome. The Human Genome Sequencing Project has provided the agricultural research community not only with many spin-off technologies that can be applied across the board for all living organisms but also with a model for international collaboration in tackling large genome-sequencing projects for model plants such as *Arabidopsis* and rice.

For a refresher course in DNA, genetics and heredity, see the interactive Web site www.dnafromthebeginning.org developed by the Cold Spring Harbor Laboratory in the United States, where much of the pioneering work in genetics and genetic engineering has been performed.

will increasingly drive the application of biotechnology in all agricultural sectors. Genomics sets the foundation for post-genomics activities, including new disciplines such as proteomics and metabolomics to generate knowledge on gene and protein structure, as well as their functions and interactions. These disciplines seek to understand systematically the molecular biology of organisms for their practical use.

A vast range of new and rapidly advancing technologies and equipment has also been developed to generate and process information about the structure and function of biological systems. The use and organization of this information is called bioinformatics. Advances in bioinformatics may allow the prediction of gene function from gene sequence data: from a listing of an organism's genes, it will become possible to build a theoretical framework of its biology. The comparison across organisms of physical and genetic maps and DNA sequences will significantly reduce the time needed to identify and select potentially useful genes.

Through the production of genetic maps that provide the precise location and sequences of genes, it is apparent that even distantly related genomes share common features (Box 5). Comparative genomics assists in the understanding of many genomes based on the intensive study of just a few. For instance, the rice genome sequence is useful for studying the genomes of other cereals with which it shares features according to its degree of relatedness, and the mouse and malaria genomes provide models for livestock and some of the diseases that affect them. There are now model species for most types of crops, livestock and diseases and knowledge of their genomes is accumulating rapidly.

Molecular markers

Reliable information on the distribution of genetic variation is a prerequisite for sound selection, breeding and conservation programmes. Genetic variation of a species or population can be assessed in the field or by studying molecular and other markers in the laboratory. A combination of the two approaches is required for reliable results. Molecular markers are identifiable DNA sequences, found at specific locations of the genome and associated with the inheritance of a trait or linked gene. Molecular markers can be used for (a) marker-assisted breeding, (b) understanding and conserving genetic resources and (c) genotype verification. These activities are critical for the genetic improvement of crops, forest trees, livestock and fish.

Marker-assisted breeding

Genetic linkage maps can be used to locate and select for genes affecting traits of economic importance in plants or animals. The potential benefits of marker-assisted selection (MAS) are greatest for traits that are controlled by many genes, such as fruit yield, wood quality, disease resistance, milk and meat production, or body fat, and that are difficult, time-consuming or expensive to measure. Markers can also be used to increase the speed or efficiency of introducing new genes from one population to another, for example when wishing to introduce genes from wild relatives into modern plant varieties. When the desired trait is found within the same species (such as two varieties of millet – Box 6), it may be transferred with traditional breeding methods, with molecular markers being used to track the desired gene.

Measuring and conserving genetic diversity

The use of molecular markers to measure the extent of variation at the genetic level, within and among populations, is of value in guiding genetic conservation activities and in the development of breeding populations in crops, livestock, forestry and fisheries. Studies carried out using these technologies in fish and forest tree species have revealed high levels of genetic variation both among and within populations. Livestock species are characterized by a high degree of genetic variation within populations, whereas crops exhibit a higher degree of variation across species. Data from other approaches, for example field observation, often cannot provide such information or are extremely difficult to collect.

Molecular markers are increasingly used to study the distribution and patterns of genetic diversity. Global surveys indicate, for example, that 40 percent of the remaining

BOX 5
Synteny is life!

Mike Gale[1]

Synteny describes the conservation or consistency of gene content and gene order along the chromosomes of different plant genomes. Until well into the 1980s we imagined that each crop plant had its own genetic map. Only when we were able to make the first molecular maps, using a technique called "restriction fragment length polymorphism" (RFLP), did it begin to dawn on us that related species had remarkably similar gene maps. The early experiments demonstrated conservation over a few million years of evolution in syntenous relationships between potato and tomato in the broad-leafed plants and between the three genomes of bread wheat in the grasses. Later we were able to show that the same similarities held over the rice, wheat and maize genomes, which were separated by some 60 million years of evolution. The diagram summarizes this research and shows 70 percent of the world's food linked in a single map. The 12 chromosomes of rice can be aligned with the ten chromosomes of maize and the basic seven chromosomes of wheat and barley in such a way that any radius drawn around the circles will pass through different versions, known as alleles, of the same genes.

The discovery of synteny has had an enormous impact on the way we think about plant genetics. There are obvious applications for evolutionary studies; for example, the white arrows on the wheat and maize circles describe evolutionary chromosomal translocations that describe *Pooideae* and *Panicoideae* groups of grasses. There are great opportunities to predict the presence and location of a gene in one species from what we know from another. Now that we have the complete DNA sequence of rice we are able to identify and isolate key genes from large genome intractable species such as wheat and barley by predicting that the same genes will be present in the same order as in rice. Key genes for disease resistance and tolerance to acid soils have recently been isolated from barley and rye in this way. For practical plant breeding, knowledge of synteny allows breeders access to all alleles in,

[1] *Professor Gale is Deputy Director of the John Innes Centre, Norwich, United Kingdom.*

domestic livestock breeds are at risk of extinction. Most of these breeds are found only in developing countries, and there is often little knowledge about them or of their potential for improvement. They may contain valuable genes that confer adaptation or resilience to stresses, such as heat tolerance or disease resistance, that may be of use for future generations. Modern biotechnologies can help to counteract trends of genetic erosion in all food and agriculture sectors.

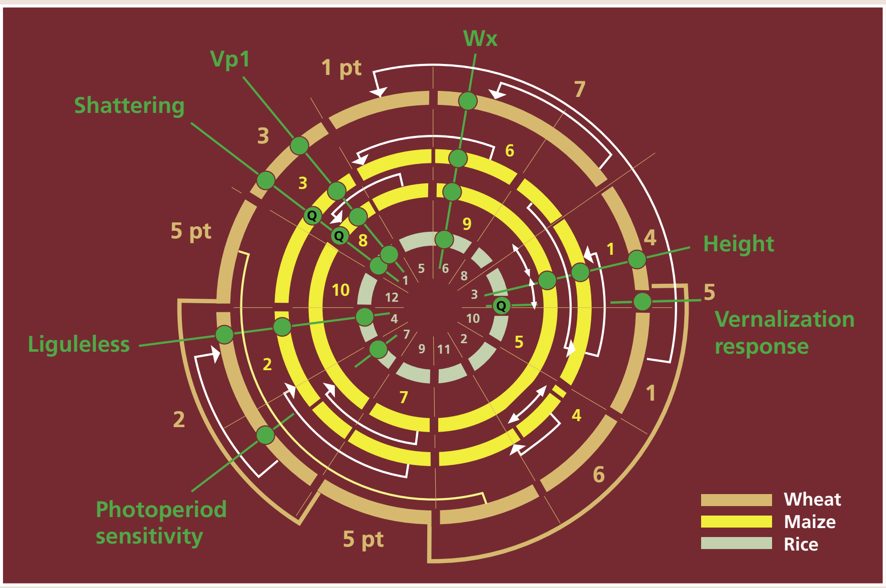
Genotype verification

Molecular markers have been widely used for identifying genotypes and for "genetic fingerprinting" of organisms. Genetic fingerprinting has been used in advanced tree-breeding programmes in which the correct identification of clones for large-scale propagation programmes is essential. Molecular markers have been used to identify endangered marine species that are either inadvertently captured in wild fisheries or that are purposefully taken illegally. Genotype verification is used intensively in parentage testing of domestic animals and for tracing livestock products in the food chain back to the farm and animal of origin.

Breeding and reproducing crops and trees

In addition to MAS, described above, a number of biotechnologies are used in breeding and reproducing crops and

for example, all cereals rather than just the species on which they are working. A key first example of this is the transfer to rice of the wheat dwarfing genes that made the Green Revolution possible. In these experiments the gene was located in rice by synteny and then isolated and engineered with the alteration in DNA sequence that characterized the wheat genes before replacing the engineered gene in rice. This approach can be applied to any gene in any cereal, including the so-called "orphan crops" that have not attracted the research dollars that the big three – wheat, rice and maize – have over the past century. The main significance is, however, that we can now pool our knowledge of biochemistry, physiology and genetics and transfer it between crops via synteny.



BOX 6
Molecular markers and marker-assisted selection for pearl millet in India

Tom Hash[1]

Pearl millet is a cereal grown for foodgrain and straw in the hottest, driest areas of Africa and Asia where rainfed and dryland agriculture are practised. It is similar to maize in its breeding behaviour. Traditional farmers' varieties are open-pollinated and out-breeding and thus continuously changing. Genetically uniform hybrid varieties have been developed that offer higher yield potential but are more vulnerable to a plant disease called downy mildew. In India, pearl millet is grown on about 9 million ha and more than 70 percent of this is sown to such hybrid cultivars. Since pearl millet hybrids first reached farmers' fields in India in the late 1960s, every variety that has become popular with farmers has ultimately succumbed to a downy mildew epidemic. Unfortunately, by the time the poorer farmers in a given region decide to adopt a particular variety, its days are usually numbered.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) wanted to reduce the risks associated with adoption of higher-yielding pearl millet hybrids and extend the useful economic life of these varieties, especially for poorer producers. Biotechnology helped us to achieve this. With tools from the John Innes Centre and support from the Plant Sciences Research Programme of the Department for International Development (DFID), we developed and applied molecular genetic tools for pearl millet. We mapped the genomic regions of pearl millet that control downy mildew resistance, straw yield potential, and grain and straw yield under drought stress conditions. Then our millet breeders used conventional breeding and marker-assisted selection (MAS) to transfer several genomic regions conferring improved downy mildew resistance to the two elite inbred parental lines of popular hybrid HHB 67. We then used MAS to derive two new varieties – ICMR 01004 and ICMR 01007 – with two different downy mildew resistance gene blocks.

These varieties have performed as well or better than their parent lines for grain and straw yield, and are markedly improved for downy mildew resistance. They also retain several favourable traits, including 1 000-grain mass, panicle length, plant height and rust resistance. Hybrids based on crosses involving ICMR 01004 and ICMR 01007 have recently advanced to trials in the Indian states of Gujarat, Rajasthan and Haryana under the All India Coordinated Pearl Millet Improvement Project. This follows their successful evaluation in 2002, in which they exhibited marginal grain yield superiority and substantially better downy mildew resistance than HHB 67, while maintaining the early maturity that contributes to its popularity.

At least one of these two hybrids could be released as a replacement for HHB 67 before the latter succumbs (as it surely will) to a downy mildew epidemic. Because HHB 67 is so widely grown by poor farmers in India, if its timely replacement could prevent such an epidemic for even one year, the losses avoided would exceed the total value of research-funding support by DFID for the development and application of the molecular genetic tool kit for pearl millet (£3.1 million to date). All future benefits from this research by ICRISAT, its DFID-supported partners in the United Kingdom, and collaborating national programme partners in India can then be considered profits to society.

---

[1] *Tom Hash is Principal Scientist (Molecular Breeding) at ICRISAT, Patancheru, Andhra Pradesh, India.*

trees. Often these technologies are used in combination with each other and with conventional breeding approaches.

Cell and tissue culture and micropropagation

Micropropagation involves taking small sections of plant tissue, or entire structures such as buds, and culturing them under artificial conditions to regenerate complete plants. Micropropagation is particularly useful for maintaining valuable plants, breeding otherwise difficult-to-breed species (e.g. many trees), speeding up plant breeding and providing abundant plant material for research. For crop and horticultural species, micropropagation is now the basis of a large commercial industry involving hundreds of laboratories around the world. In addition to its rapid propagation advantages, micropropagation can also be used to generate disease-free planting material (Box 7), especially if combined with the use of disease-detection diagnostic kits. There have been some attempts to use micropropagation more widely in forestry. Compared with vegetative propagation through cuttings, the higher multiplication rates available through micropropagation offer a more rapid dissemination of planting stock, although limited availability of desirable clones is an impediment to its wider adoption in forestry.

In vitro selection

In vitro selection refers to the selection of germplasm by applying specific selection pressure to tissue culture under laboratory conditions. Many recent publications have reported useful correlations between *in vitro* responses and the expression of desirable field traits for crop plants, most commonly disease resistance. Positive results are available also for tolerance to herbicides, metals, salt and low temperatures. For the selection criteria of major general importance in forest trees (in particular vigour, stem form and wood quality), poor correlations with field responses still limit the usefulness of *in vitro* selection. However, this method may be of interest in forestry programmes for screening disease resistance and tolerance to salt, frost and drought.

Genetic engineering

When the desired trait is found in an organism that is not sexually compatible with the host, it may be transferred using genetic engineering. In plants, the most common method for genetic engineering uses the soil bacterium *Agrobacterium tumefasciens* as a vector. Researchers insert the desired gene or genes into the bacterium and then infect the host plant. The desired genes are transmitted to the host along with the infection. This method is used mainly with dicot species such as tomato and potato. Some crops,

BOX 7

Micropropagation of disease-free banana in Kenya

Banana is generally grown in developing countries where it is a source of employment, income and food. Banana production is in decline in many regions because of pest and disease problems that cannot be addressed successfully through agrochemical control for reasons of cost and negative environmental effects. The problem is exacerbated because banana is reproduced clonally; the use of diseased mother plants therefore gives rise to diseased offspring.

Micropropagation represents a means of regenerating disease-free banana plantlets from healthy tissue. In Kenya, banana shoot tips have been successfully tissue-cultured. An original shoot tip is heat-treated to destroy infective organisms and then used through many cycles of regeneration to produce daughter plants. A single section of tissue can be used to produce as many as 1 500 new plants through ten cycles of regeneration.

Micropropagation of banana has had a tremendous impact in Kenya, among many other countries, contributing to improved food security and income generation. It has all the advantages of being a relatively cheap and easily applied technology and one that brings significant environmental benefits.

particularly monocot species such as wheat and rye, are not naturally susceptible to transformation via *A. tumefasciens*, although the method has recently been successfully used to transform wheat and other cereals. In the most common transformation technique for these crops, the desired gene is coated on gold or tungsten particles and a "gene gun" is used literally to shoot the gene into the host at high velocity.

Three distinctive types of genetically modified crops exist: (a) "distant transfer", in which genes are transferred between organisms of different kingdoms (e.g. bacteria into plants); (b) "close transfer", in which genes are transferred from one species to another of the same kingdom (e.g. from one plant to another); and (c) "tweaking", in which genes already present in the organism's genome are manipulated to change the level or pattern of expression. Once the gene has been transferred, the crop must be tested to ensure that the gene is expressed properly and is stable over several generations of breeding. This screening can usually be performed more efficiently than for conventional crosses because the nature of the gene is known, molecular methods are available to determine its localization in the genome and fewer genetic changes are involved.

Most of the transgenic crops planted so

BOX 8

Agriculture on acid soils: improving aluminium tolerance in cereals

Miftahudin,[1,2] M.A. Rodriguez Milla,[2] K. Ross[3] and J.P. Gustafson[3]

Aluminium in acid soils limits plant growth on more than 30 percent of all arable land, primarily in developing countries. There are two approaches to increasing crop production on acid soils. Lime can be added to the soil to increase the pH, but this is a costly, temporary measure. Alternatively, genetically improved cultivars, tolerant to aluminium, can be developed. Existing wheat cultivars do not contain significant genetic variation for increasing aluminium tolerance. Improved tolerance will have to be introduced into wheat from the gene pools of related, more tolerant species. A genetic linkage map of wheat was developed using available markers for the existing aluminium-tolerance gene.

Rye exhibits a fourfold increase in aluminium tolerance over wheat. Therefore, a rye gene controlling aluminium tolerance was characterized. Markers from wheat, barley and rice were used to establish a tight linkage, flanking the rye gene, and to construct a high-resolution genetic map. A potential candidate gene was used for root-gene-expression, time-course studies that showed expression in rye roots only under aluminium stress.

Targeting the aluminium tolerance gene is one example of using problem-based approaches to integrate molecular and breeding tools to improve wheat production. Using the genetic relationship (synteny) among the cereals to supply markers to identify and characterize value-added traits, complementary approaches for improved wheat production emerge. Breeders can use the markers flanking the rye gene in marker-assisted breeding programmes in areas where GMOs cannot be grown or where only conventional breeding tools are available. In addition, these markers can be used for map-based cloning to isolate the gene in question for transgenic approaches to wheat improvement. Finally, the use of syntenous relationships offers the technology to manipulate many value-added traits for crop improvement in other species.

[1] *Department of Agronomy, University of Missouri, Columbia, United States.*
[2] *Department of Biology, Bogor Agricultural University, Bogor, Indonesia.*
[3] *United States Department of Agriculture Agricultural Research Service, Plant Genetics Research Unit, and Department of Agronomy, University of Missouri, Columbia, United States.*

far have incorporated only a very limited number of genes aimed at conferring insect resistance and/or herbicide tolerance (see Chapter 3 for more information regarding the transgenic crops that are currently being researched and grown commercially). However, some transgenic crops and traits of greater potential interest for developing countries have been developed but have not yet been released commercially. Box 8 describes one research project to improve the tolerance of wheat to aluminium, a problem that affects acid soils in much of Africa and Latin America. Similar work is being performed to improve the tolerance of plants to other stresses such as drought, saline soils and temperature extremes.

Nutritionally enhanced crops could make a significant contribution to the reduction of micronutrient malnutrition in developing countries. Biofortification (the development of nutritionally enhanced foods) can be advanced through the application of several biotechnologies in combination. Genomic analysis and genetic linkage mapping are needed to identify the genes responsible for natural variation in nutrient levels of common foods (Table 2). These genes can then be transferred into familiar cultivars through conventional breeding and MAS or, if sufficient natural variation does not occur within a single species, through genetic engineering. Non-transgenic approaches are being used, for example, to enhance the protein content in maize, iron in rice, and carotene in sweet potato and cassava.

Genetic engineering can be used when insufficient natural variation in the desired nutrient exists within a species. Box 9 describes the debate surrounding a project to enhance the protein content of potato using genetic engineering. The well-known transgenic Golden Rice contains three foreign genes – two from the daffodil and one from a bacterium – that produce provitamin A (see Box 13 on page 42). Scientists are well on their way to developing transgenic "nutritionally optimized"' rice that would contain genes producing provitamin A, iron and more protein (Potrykus, 2003). Other nutritionally enhanced foods are under development, such as oils with reduced levels of undesirable fatty acids. In addition, foods that are commonly allergenic (shrimp, peanuts, soybean, rice, etc.) are being modified to contain lower levels of allergenic compounds.

A major technical factor limiting the application of genetic modification to forest trees is the current low level of knowledge regarding the molecular control of traits that are of most interest. One of the first reported trials with genetically modified forest trees was initiated in Belgium in 1988 using poplars. Since then, there have been more

TABLE 2

Genetic variation in concentrations of iron, zinc, beta-carotene and ascorbic acid found in germplasm of five staple foods, dry weight basis

	(mg/kg)			
	Iron	Zinc	Beta-carotene[1]	Ascorbic acid
RICE				
Brown	6–25	14–59	0–1	–
Milled	1–14	14–38	0	–
CASSAVA				
Root	4–76	3–38	1–24[2]	0–380[2]
Leaves	39–236	15–109	180–960[2]	17–4200[2]
BEAN	34–111[1]	21–54	0	–
MAIZE	10–63	12–58	0–10	–
WHEAT	10–99[3]	8–177[2]	0–20	–

[1] Range for total carotenoids is much greater.
[2] Fresh weight basis.
[3] Including wild relatives.
Source: International Center for Tropical Agriculture (CIAT), 2002.

BOX 9
The "protato": help for the poor or a Trojan horse?

Researchers at Jawaharlal Nehru University in India have developed a genetically engineered potato that produces about one-third to one-half more protein than usual, including substantial amounts of all the essential amino acids such as lysine and methionine. Protein deficiency is widespread in India and potato is the staple food of the poorest people.

The "protato" was developed by a coalition of Indian charities, scientists, government institutes and industry as part of a 15-year campaign against childhood mortality. The campaign aims to eliminate childhood mortality by providing children with clean water, better food and vaccines.

The protato includes a gene from the amaranth plant, a high-protein grain that is native to South America and widely sold in Western health-food stores. The protato has passed preliminary field trials and tests for allergens and toxins. Final approval from the Indian Government is probably at least five years away.

Supporters such as Govindarajan Padmanaban, a biochemist at the Indian Institute of Science, argue that the protato can provide an important nutritional boost to children with little danger of allergy because potatoes and amaranth are both already widely consumed. There is also little threat to the environment because neither potatoes nor amaranth have wild relatives in India, and the protato does not involve any change in normal potato production practices. Furthermore, because the protato was developed by public-sector scientists in India, there are no concerns about foreign corporate control of the technology. Given these benefits, Padmanaban commented: "I think it would be morally indefensible to oppose it" (Coghlan, 2003).

Opponents such as Charlie Kronick of Greenpeace argue that potatoes are naturally quite low in protein (about 2 percent), so even a doubling of the protein content would make only a minute contribution to India's malnutrition problem. He claims that the effort to develop the protato was aimed more at gaining public acceptance of genetic engineering than at addressing the problem of malnutrition: "The cause of hunger isn't lack of food. It's lack of cash and of access to the food. Creating these GM crops is something to make them look attractive when actually the utility of eating them is very, very low. It's very difficult to see how this on its own will change the face of poverty" (Charles, 2003).

than 100 reported trials involving at least 24 tree species, primarily timber-producing species. Traits for which genetic modification has been contemplated for forest trees include insect and virus resistance, herbicide tolerance and lignin content. Reduction of lignin is a valuable objective for species producing pulp for the paper industry because it would enable a reduction in the use of chemicals in the process.

Breeding and reproducing livestock and fish

Biotechnology has long been a source of innovation in livestock and aquaculture production and processing and has had a profound impact on both sectors. Rapid advances in molecular biology and further developments in reproductive biology provide new and powerful tools for further innovation. Technologies such as genomics and molecular markers, as described above, are valuable in understanding, characterizing and managing genetic resources in livestock and fisheries as well as in crops and forestry (Box 10). Genetic engineering is also relevant in livestock and fisheries, although the techniques differ, and additional reproductive technologies are available in these sectors. This section describes the reproductive biotechnologies that are specific to the livestock and fisheries sectors.

BOX 10
State of the World's Animal Genetic Resources

FAO has been requested by its member countries to develop and implement the Global Strategy for the Management of Farm Animal Genetic Resources. As part of this country-driven strategy for the management of farm animal genetic resources, FAO invited 188 countries to participate in preparing the First Report on the State of the World's Animal Genetic Resources, to be completed before 2006. To date, 145 countries have agreed to submit country reports and 30 country reports have been received and analysed (Cardellino, Hoffmann and Templeman, 2003). It is clear from these reports that artificial insemination (AI) is the most common biotechnology used by developing countries in the livestock sector. Many countries have requested training for the expansion of AI use, while expressing concerns that it has often been introduced without proper planning and may pose a potential threat to the conservation of local breeds. Although the use of multiple ovulation followed by embryo transfer (MOET) is mentioned and the desire for its introduction or expansion expressed, no clear objectives for this technique are mentioned. All countries have expressed the wish to introduce and develop molecular techniques, often as a complement to phenotypic breed characterization. Cryoconservation was identified as a priority by all countries and gene banks were recommended, but funding remains a major constraint. When animal GMOs are mentioned it is mainly to express the lack of proper regulations and guidelines for their eventual production, use and exchange. Some countries have expressed concerns that biotechnologies in the livestock sector should be, but are not always, pursued as an integral part of an overall genetic improvement strategy.

The main objective of reproductive biotechnologies for livestock is to increase reproductive efficiency and rates of animal genetic improvement. The genetic improvement of locally adapted breeds will be important in realizing sustainable production systems within the broad spectrum of developing country production environments, and will probably best be realized by the strategic use of both non-genetic and genetic interventions. Reproductive biotechnology in fisheries presents opportunities to increase growth rates and improve the management of farmed species and to limit the reproductive potential of genetically engineered species.

Artificial insemination and multiple ovulation/embryo transfer

Advances in artificial insemination (AI) and multiple ovulation followed by embryo transfer (MOET) have already had a major impact on livestock improvement programmes in developed countries and many developing countries because they speed up the process of genetic improvement, reduce the risk of disease transmission and expand the number of animals that can be bred from a superior parent – the male in the case of AI and the female in the case of MOET. They also increase the incentives for private research in animal breeding and significantly expand the market for improved parent stock.

The number of AIs performed globally during 1998 was over 100 million in cattle (primarily dairy cattle, including buffalo), 40 million in pigs, 3.3 million in sheep and 0.5 million in goats. These figures illustrate both the higher economic returns in dairy cattle and the fact that cattle semen is much easier to deep-freeze than semen from other animals. Although over 60 million cattle AIs were performed in South and Southeast Asia, fewer than 1 million were performed in Africa.

AI is only effective when the farm sector has access to considerably greater technical and institutional and other organizational capacity than when male animals are used directly for breeding purposes. On the positive side, farmers employing AI do not have to face the costs or hazards of rearing breeding males and can have access to semen from any part of the world.

Despite the widespread use of AI in developed countries and in many developing countries, including within more advanced smallholder systems, it is applied only on farms that practise intensive livestock management with high-value animals. This is clearly not because of technical problems with semen production and storage, as most procedures are now fully standardized and proven to be effective under tropical developing-country conditions. Rather, it is because of the many organizational, logistical and farmer-training constraints that influence the quality and efficiency of the technology.

MOET takes AI one step further, both in terms of genetic gains possible and level of technical capacity and organization required. MOET is one of the basic technologies for the application of more advanced reproductive biotechnologies such as cloning and transgenics. During 2001 the number of embryos transferred globally was 450 000, mainly in dairy cattle, with North America and Europe accounting for 62 percent, followed by South America (16 percent) and Asia (11 percent). About 80 percent of the bulls used in AI are derived from MOET. The main potential advantage of MOET for developing countries will be in the possibility of importing frozen embryos instead of live animals, for example in the establishment of nucleus breeding stocks of locally adapted genetic resources, with the related lower sanitary risks.

Chromosome-set manipulation and sex reversal in fish

Controlling the sex and reproductive capacity of fish can be important for commercial and environmental reasons. One sex is often more desirable than the other; for example, only female sturgeon produce caviar and male tilapia grow faster than females. Sterility may be desirable when reproduction affects the taste of the product (e.g. oysters) or when farmed species (transgenic or not) might breed with wild populations. Chromosome-set manipulation and sex reversal are well-established techniques to control these factors. In chromosome-set manipulation, temperature, chemical and pressure shocks applied to fish eggs can be used to produce individuals that have three sets of chromosomes rather than the usual two. These triploid organisms generally do not channel energy into reproduction and thus are functionally sterile. Sex reversal can be accomplished by several methods including administering appropriate hormones. For example, genetically male tilapia can be turned into females through oestrogen treatments. These genetic males, when mated with normal males, produce a group of all-male tilapia.

Genetic engineering in livestock and fish

Genetic engineering in animals can be used to introduce foreign genes into the animal genome or, alternatively, to "knock-out" selected genes. The method most used at present involves direct microinjection of DNA into the pronuclei of fertilized eggs, but progress is being made with new approaches such as nuclear transfer and the use of lentiviruses as DNA vectors.

In the first genetic engineering experiments with farm animals, genes responsible for growth were introduced into pigs to increase growth and improve carcass quality. Current research efforts include engineering resistance to animal diseases, such as Marek's disease in poultry, scrapie in sheep and mastitis in cattle, and diseases that affect human health such as *Salmonella* in poultry. Other examples include increasing the casein content of milk and inducing the production of pharmaceutical or industrial chemicals in the milk or semen of animals. Although conceptually simple, the methods used to genetically engineer livestock require special equipment and considerable dexterity, and no agricultural applications have proved commercially successful thus far. Applications in the near future therefore seem to be limited to the production of transgenic animals for use in the production of industrial or pharmaceutical products.

Genetic engineering is an active area of research and development in aquaculture. The large size and hardy nature of many fish eggs allow them to be manipulated easily and facilitate gene transfer by direct injection of a foreign gene or by electroporation, in which an electric field assists gene transfer. Gene transfer in fish has usually involved genes that produce growth hormone and has been shown to increase growth rates dramatically in carp, salmon, tilapia and other species. In addition, a gene from the winter flounder that produces an antifreeze protein was put into salmon in the hope of extending the farming range of the fish. The gene did not produce enough of the protein to extend the salmon's range into colder waters, but it did allow the salmon to continue growing during cold months when non-transgenic salmon would not grow. These applications are still in the research and development stage, and no transgenic aquatic animals are currently available to the consumer.

Other biotechnologies

Diagnostics and epidemiology

Plant and animal diseases are difficult to diagnose because the signs may be misleading or even entirely absent until serious damage has occurred. Advanced biotechnology-based diagnostic tests make it possible to identify disease-causing agents and to monitor the impact of disease control programmes to a degree of precision not previously possible. Molecular epidemiology characterizes pathogens (viruses, bacteria, parasites and fungi) by nucleotide sequencing, which enables their origin to be traced. This is particularly important for epidemic diseases, in which the possibility of pinpointing the source of infection can significantly contribute to improved disease control. For example, the molecular analysis of rinderpest viruses has been vital for determining the lineages circulating in the world and instrumental in aiding the Global Rinderpest Eradication Programme (GREP) (Box 11). Enzyme-linked immunosorbent assay (ELISA) tests have become the standard methodology for the diagnosis and surveillance of many animal and fish diseases worldwide, and the polymerase chain reaction (PCR) technique is especially useful in diagnosing plant diseases and is proving increasingly so also for livestock and fish diseases. The effectiveness of plant and animal health programmes is also being considerably enhanced by the development of genetic probes that allow specific pathogens to be distinguished and detected in tissue, whole animals and even in water and soil samples.

Vaccine development

Genetically engineered vaccines are being developed to protect fish and livestock against pathogens and parasites. Although vaccines developed using traditional approaches have had a major impact on the control of foot-and-mouth and tick-borne diseases, rinderpest and other diseases affecting livestock, recombinant vaccines can offer various advantages over conventional vaccines in terms of safety, specificity and stability. Importantly, such vaccines, coupled with the appropriate diagnostic test, allow the distinction between vaccinated and naturally infected animals. This is important in disease control programmes as it enables continued vaccination even when the shift from the control to the eradication stage is contemplated.

Today, quality improved vaccines are available for, for example, Newcastle disease, classical swine fever and rinderpest. In addition to the technical improvements, advances in biotechnology will make vaccine production cheaper, and therefore improve supply and availability for smallholders.

Animal nutrition

Biotechnologies have already resulted in animal nutrition aids such as enzymes, probiotics, single-cell proteins and antibiotic feed additives that are already widely used in intensive production systems worldwide to improve the availability of nutrients from feeds and the productivity of livestock and aquaculture. Gene-based technologies are being increasingly employed to improve animal nutrition, either through modifying the feeds to make them more digestible or through modifying the digestive and metabolic systems of animals to enable them to make better use of the available feeds. Although progress in the latter approach is likely to be slow because of gaps in our current understanding of the underlying genetics, physiology and biochemistry, one example of commercial success in high-input, intensively managed systems is the use of

BOX 11
Biotechnology: ridding the world of rinderpest

Rinderpest, one of the world's most devastating livestock diseases, is a serious threat to millions of small-scale farmers and pastoralists who depend on cattle for their food and livelihoods. This viral disease, which affects cattle including buffalo, yak and related wildlife species, destroyed nearly 90 percent of all cattle in sub-Saharan Africa in the 1890s. An epidemic between 1979 and 1983 killed more than 100 million head of cattle in Africa – more than 500 000 in Nigeria alone – causing estimated losses of $1.9 billion. Asia and the Near East have also been badly affected by this disease.

Today, the world is almost free of rinderpest: Asia and the Near East are believed to be free of the virus and strenuous efforts are being made to ensure that it does not break out of its last possible focus – believed to be the Somali pastoral ecosystem that encompasses northeastern Kenya and southern Somalia. The goal of complete freedom from rinderpest is within our grasp. Rinderpest would be only the second disease to be eradicated worldwide, after smallpox.

The progress seen so far has been a remarkable triumph for veterinary science, and a powerful example of what can be achieved when the international community and individual countries, their veterinary services and farming communities, cooperate to develop and implement results-based policies and strategies for seeing them through. The Pan African Rinderpest Eradication Campaign (PARC), overseen by the African Union, and the Global Rinderpest Eradication Programme (GREP), overseen by FAO, are the key coordinating institutions in the battle against rinderpest.

Biotechnology is at the heart of this effort. First, it enabled the development and large-scale production of the vaccines used to protect many millions of animals through national mass vaccination campaigns. The initial vaccine, which was developed by Dr Walter Plowright and colleagues in Kenya with support from the United Kingdom, was based on a virus that was attenuated by successive passages in tissue culture. Dr Plowright was awarded the World Food Prize in 1999 for this work. Although highly effective and safe, this vaccine lost some of its potency when exposed to heat. Further research was therefore directed at developing a thermostable vaccine for use in remote areas. Success was achieved through research in Ethiopia by Dr Jeffery Mariner supported by the United States Agency for International Development (USAID).

Secondly, biotechnology provided the technological platform (ELISA,

recombinant somatotropin, a hormone that results in increased milk production in dairy cows and accelerated growth and leaner carcasses in meat animals.

Conclusions

Biotechnology is a complement – not a substitute – for many areas of conventional agricultural research. It offers a range of tools to improve our understanding and management of genetic resources for food and agriculture. These tools are already making a contribution to breeding and conservation programmes and to facilitating the diagnosis, treatment and prevention of plant and animal diseases. The application of biotechnology provides the researcher with new knowledge and tools that make the job more efficient and effective. In this way, biotechnology-based research programmes can be seen as a more precise extension of conventional approaches (Dreher *et al.*, 2000). At the same time, genetic engineering can be seen as a dramatic departure from conventional breeding because it gives scientists the power to move genetic material between organisms that could not be bred through classical means.

chromatographic pen-side systems and molecular tests) to detect and identify viruses and monitor the effectiveness of vaccination campaigns. Before these techniques and the necessary sampling and testing strategies, which were developed by FAO and the International Atomic Energy Agency (IAEA) with support from the Swedish International Development Cooperation Agency (SIDA), vaccinated animals could not be distinguished from infected ones, so countries could not demonstrate that they were free of rinderpest. As a result, they had to conduct costly annual vaccination programmes indefinitely while they continued to suffer from restrictions on animal movement and trade that were imposed to avoid the spread of the disease.

The economic impact of these efforts is already clearly apparent. Although the cost of vaccination and blood sampling and testing has been high for both developing and developed nations, the effectiveness of national campaigns and regional and global coordination is demonstrated by the fact that there is only one small focus of disease outbreaks still occurring around the world. By contrast, in 1987, for example, the disease was present in 14 African countries as well as in Pakistan and some countries in the Near East.

Although costs and benefits vary considerably from country to country, the figures for Africa illustrate the cost-effectiveness of PARC and GREP. Major outbreaks of rinderpest normally last for five years and result in a total mortality of 30 percent. With a total cattle population of 120 million in sub-Saharan Africa, this represents about 8 million head of cattle per year. At an estimated value per head of $120, the cost of another major rinderpest outbreak would be around $960 million. Under PARC, about 45 million head of cattle were vaccinated each year at a cost of $36 million, and the costs of serological monitoring and surveillance were around $2 million. This gives an annual cost–benefit ratio of around 22 : 1 and a net annual economic benefit to the region of at least $920 million.

PARC and GREP have also provided other significant benefits. Not least of these is that through the policies, strategies and institutional arrangements put in place to tackle rinderpest, and that have enabled effective linkages to be established among farmers, field and laboratory personnel and national authorities, they have opened up opportunities for countries to move on and tackle the challenges of controlling or eradicating other diseases affecting livestock and food security in the world.

Agricultural biotechnology is cross-sectoral and interdisciplinary. Most of the molecular techniques and their applications are common across all sectors of food and agriculture, but biotechnology cannot stand on its own. Genetic engineering in crops, for example, cannot proceed without knowledge derived from genomics and it is of little practical use in the absence of an effective plant-breeding programme. Any single research objective requires mastery of a bundle of technological elements. Biotechnology should be part of a comprehensive, integrated agricultural research programme that takes advantage of work in other sectoral, disciplinary and national programmes. This has broad implications for developing countries and their development partners as they design and implement national research policies, institutions and capacity-building programmes (see Chapter 8).

Agricultural biotechnology is international. Although most of the basic research in molecular biology is taking place in developed countries (see Chapter 3), this research can be beneficial for developing countries because it provides insight into the physiology of all plants and animals. The findings of the human and the mice genome projects provide direct benefits for farm animals, and vice versa, whereas studies of maize and rice can provide parallels for applications in subsistence crops such as sorghum and tef. However, specific work is needed on the breeds and species of importance in developing countries. Developing countries are host to the greatest array of agricultural biodiversity in the world, but little work has been done on characterizing these plant and animal species at the molecular level to assess their production potential and their ability to resist disease and environmental stresses or to ensure their long-term conservation.

The application of new molecular biotechnologies and new breeding strategies to the crops and livestock breeds of specific relevance to smallholder production systems in developing countries will probably be constrained in the near future for a number of reasons (see Chapters 3 and 7). These include lack of reliable longer-term research funding, inadequate technical and operational capacity, the low commercial value of the crops and breeds, lack of adequate conventional breeding programmes and the need to select in the relevant production environments. Nevertheless, developing countries are already faced with the need to evaluate genetically modified (GM) crops (see Chapters 4–6) and they will one day also need to evaluate the possible use of GM trees, livestock and fish. These innovations may offer opportunities for increased production, productivity, product quality and adaptive fitness, but they will certainly create challenges for the research and regulatory capacity of developing countries.

3. From the Green Revolution to the Gene Revolution

The Green Revolution brought high-yielding semi-dwarf wheat and rice varieties, developed with conventional breeding methods, to millions of small-scale farmers, initially in Asia and Latin America, but later in Africa as well. The gains achieved during the early decades of the Green Revolution were extended in the 1980s and 1990s to other crops and to less favoured regions (Evenson and Gollin, 2003). In comparison with the research that drove the Green Revolution, the majority of agricultural biotechnology research and almost all of the commercialization is being carried out by private firms based in industrialized countries.

This is a dramatic departure from the Green Revolution, in which the public sector played a strong role in research and technology diffusion. This paradigm shift has important implications for the kind of research that is performed, the types of technologies that are developed and the way these technologies are disseminated. The dominance of the private sector in agricultural biotechnology raises concerns that farmers in developing countries, particularly poor farmers, may not benefit – either because appropriate innovations are not available or are too expensive.

Public-sector research was responsible for creating the high-yielding varieties of wheat and rice that launched the Green Revolution. International and national public-sector researchers bred dwarfing genes into elite wheat and rice cultivars, causing them to produce more grain and have shorter stems and enabling them to respond to higher levels of fertilizer and water. These semi-dwarf cultivars were made freely available to plant breeders from developing countries who further adapted them to meet local production conditions. Private firms were involved in the development and commercialization of locally adapted varieties in some countries, but the improved germplasm was provided by the public sector and disseminated freely as a public good (Pingali and Raney, 2003).

The countries that were able to make the most of the opportunities presented by the Green Revolution were those that had, or quickly developed, strong national capacity in agricultural research. Researchers in these countries were able to make the necessary local adaptations to ensure that the improved varieties suited the needs of their farmers and consumers. National agricultural research capacity was a critical determinant of the availability and accessibility of Green Revolution agricultural technologies, and this remains true today for new biotechnologies. National research capacity increases the ability of a country to import and adapt agricultural technologies developed elsewhere, to develop applications that address local needs (e.g. "orphan crops") and to regulate new technologies appropriately.

The biotechnology revolution, by contrast, is being driven largely by the private sector. Public-sector research has contributed to the basic science underpinning agricultural biotechnology, but the private sector is responsible for most applied research and almost all commercial development. Three interrelated forces are transforming the system for providing improved agricultural technologies to the world's farmers. The first is the strengthening environment for protecting intellectual property in plant innovations. The second is the rapid pace of discovery and the growing importance of molecular biology and genetic engineering. Finally, agricultural input and output trade is becoming more open in nearly all countries, enlarging the potential market for new technologies and older related technologies. These developments have created powerful new incentives for private research, and are altering the structure of the public/private agricultural research endeavour, particularly with respect to crop improvement (Pingali and Traxler, 2002).

SPECIAL CONTRIBUTION 1

Feeding 10 billion people – our twenty-first century challenge

Norman E. Borlaug[1]

During the past 35 years, cereal production has more than doubled, expanding faster than world population growth. Rapid adoption of modern varieties, a threefold increase in chemical fertilizer consumption and a doubling in irrigated area were key factors driving this Green Revolution. By increasing yields on the lands best suited to agriculture, world farmers have been able to leave untouched vast areas of land for other purposes.

The world population may reach 10 billion by the middle of this century. Over the next 20 years, world cereal demand will increase by 50 percent, driven by rapidly growing animal feed use and meat consumption. With the exception of acid-soil areas in Africa and South America, the potential for expanding global crop area is limited. Future expansions in food output must come largely from land already in use. The productivity of this land must be sustained and improved.

Most of the world's 842 million hungry people live in marginal lands and depend upon agriculture for their livelihoods. Food-insecure households in these higher-risk rural areas face frequent droughts, degraded lands, remoteness from markets and poor market institutions. For many of these people, food security will only come through increased agricultural production and income. Investments in science, infrastructure and resource conservation are needed to increase productivity and lower risks in marginal lands. Some of the problems in such environments will be too formidable to overcome. However, significant improvements should be possible. Biotechnology will play an important role in developing new germplasm with greater tolerance to abiotic and biotic stresses and with higher nutritional content. Continued genetic improvement of food crops – using conventional research tools and biotechnology – is needed to shift the yield frontier higher and to increase stability of yield.

Neolithic man – or much more likely woman – domesticated virtually all of our food and livestock species over a relatively short period, 10 000–15 000 years ago. Subsequently, several hundred generations of farmers were responsible for making enormous genetic modifications in all of our major crop and animal species. Thanks to the development of science over the past 150 years, we now have the insights into plant genetics and breeding to do purposefully what Nature did in the past by chance or design. Genetic modification of crops is not some kind of witchcraft; rather, it is the progressive harnessing of the forces of nature to the benefit of feeding the human race. Indeed, genetic engineering – plant breeding at the molecular level – is just another step in humankind's deepening scientific journey into living genomes. It is not a replacement for conventional breeding but a complementary research tool to identify desirable traits from remotely related taxonomic groups and transfer them more quickly and precisely into high-yielding, high-quality crop species.

The world has the technology – already available or well advanced in the research pipeline – to feed on a sustainable basis a population of 10 billion people. However, access to such technology is not assured. The range of potential barriers includes issues related to intellectual property rights, technology acceptance by civil society and governments, and financial and educational barriers that keep poor farmers marginalized and unable to adopt new technology.

---

[1] *Norman Borlaug is President of the Sasakawa Africa Association, Distinguished Professor of International Agriculture, Texas A&M University, and the winner of the 1970 Nobel Peace Prize. He is known as the father of the Green Revolution for his pioneering work in wheat breeding and production.*

With the growing importance of the private transnational sector, developing countries are facing increasing transaction costs in access to and use of technologies. Existing public-sector international networks for sharing technologies across countries and thereby maximizing spillover benefits are becoming increasingly threatened. The urgent need today is for a system of technology flows that preserves the incentives for private-sector innovation while at the same time meeting the needs of poor farmers in the developing world.

The first section of this chapter presents an overview of the organization and impacts of agricultural research and technology flows in the period 1960–90, when the Green Revolution paradigm of international, public-sector research held sway. The second section discusses the movement towards the increased privatization of agricultural research and development and its consequences for developing country access to technologies as revealed in recent global trends in biotechnology research, development and commercialization. The concluding section raises a number of questions regarding the potential of the Gene Revolution to benefit the poor. These questions are taken up in the subsequent chapters of the report.

The Green Revolution: research, development, access and impact

The Green Revolution was responsible for an extraordinary period of growth in food crop productivity in the developing world over the last 40 years (Evenson and Gollin, 2003). A combination of high rates of investment in crop research, infrastructure and market development, and appropriate policy support fuelled this progress. These elements of the Green Revolution strategy improved productivity growth despite increasing land scarcity and high land values (Pingali and Heisey, 2001).

Public-sector research and international technology transfer

The Green Revolution defied the conventional wisdom that agricultural technology does not travel well because it is either agroclimatically specific, as in the case of biological technology, or sensitive to relative factor prices, as with mechanical technology (Byerlee and Traxler, 2002). The Green Revolution strategy for food-crop productivity growth was explicitly based on the premise that, given appropriate institutional mechanisms, technology spillovers across political and agroclimatic boundaries could be created. Hence the Consultative Group on International Agricultural Research (CGIAR) was established specifically to generate technology spillovers, particularly for countries that are unable to capture all the benefits of their research investments. What happens to the spillover benefits from agricultural research and development in an increasingly global integration of food supply systems?

The major breakthroughs in yield potential that kick-started the Green Revolution in the late 1960s came from conventional plant-breeding approaches that initially focused on raising yield potential for the major cereal crops. The yield potential for the major cereals has continued to rise at a steady rate after the initial dramatic shifts in the 1960s for rice and wheat. For example, yield potential in irrigated wheat has been rising at the rate of 1 percent per year over the past three decades, an increase of around 100 kg/ha/year (Pingali and Rajaram, 1999). Essentially, no research or elite germplasm was available for many of the crops grown by poor farmers in less favourable agro-ecological zones (such as sorghum, millet, barley, cassava and pulses) during the early decades of the Green Revolution, but since the 1980s modern varieties have been developed for these crops and their yield potential has risen (Evenson and Gollin, 2003). In addition to their work on shifting the yield frontier of cereal crops, plant breeders continue to have successes in the less glamorous but no less important areas of applied research. These include development of plants with durable resistance to a wide spectrum of insects and diseases, plants that are better able to tolerate a variety of physical stresses, crops that require a significantly lower number of days of cultivation, and cereal grain with enhanced taste and nutritional qualities.

Prior to 1960, there was no formal system in place that provided plant breeders with

SPECIAL CONTRIBUTION 2
Towards an evergreen revolution

M.S. Swaminathan[1]

In August 1968, the Government of India issued a stamp entitled "Wheat Revolution" to generate public awareness of the revolutionary pathway India had entered in relation to increasing wheat production. Even while highlighting the yield breakthrough in wheat, the Government had also launched a massive programme to develop and spread high-yielding varieties for rice, maize, sorghum and pearl millet. These programmes were the drivers of the "Green Revolution" in India, which permitted striking advances in production and productivity without increasing cultivated area.

Because these high-yielding varieties require inputs such as fertilizer and irrigation water, social scientists criticized the Green Revolution technologies for not being resource neutral. Environmentalists attacked the Green Revolution because of potential damage to long-term productivity as a result of excessive use of pesticides and fertilizers and monocropping. Despite the success of the Green Revolution in raising millions of people out of misery, the incidence of poverty, endemic hunger, communicable diseases, infant and maternal mortality rates, low birth-weight children, stunting and illiteracy remain high.

The concerns of social scientists and ecologists and the remaining urgent problems of poverty and hunger led to my developing the concept of an "evergreen revolution" to stress the need for enhancing crop productivity in perpetuity without associated ecological or social harm. An evergreen revolution can be achieved only if we pay attention to pathways that can help to achieve revolutionary progress in enhancing productivity, quality and value-addition under conditions of diminishing per capita arable land and irrigation water availability, expanding biotic and abiotic stresses, and fast-changing consumer and market preferences. This will require mobilizing the best in both traditional wisdom and technologies and frontier

[1] The author is the Chair of the M.S. Swaminathan Research Foundation. He has worked for the past 50 years with scientists and policy-makers on a range of problems in basic and applied plant genetics as well as in agricultural research and development. He is widely known as the father of the Green Revolution in India.

access to germplasm available beyond their borders. Since then, the international public sector (the CGIAR system) has been the predominant source of supply of improved germplasm developed from conventional breeding approaches, especially for self-pollinating crops such as rice and wheat and for open-pollinated maize. These CGIAR-managed networks evolved in the 1970s and 1980s, when financial resources for public agricultural research were expanding and plant intellectual property laws were weak or non-existent. The exchange of germplasm is based on a system of informal exchange among plant breeders that is generally open and without charge. Breeders can contribute any of their material to the nursery and take pride in its adoption elsewhere in the world, while at the same time they are free to pick material from the trials for their own use.

The international flow of germplasm has had a large impact on the speed and the cost of crop development programmes of national agricultural research systems (NARS), thereby generating enormous efficiency gains (Evenson and Gollin, 2003). Traxler and Pingali (1999) argued that the existence of a free and uninhibited system of germplasm exchange that attracts the best of international materials allows countries to make strategic decisions on the extent to which they need to invest in plant-breeding capacity. Even NARS with advanced crop research programmes, such as in Brazil, China and India, rely heavily on cultivars taken from these nurseries for their prebreeding material and for finished science. Among the frontier technologies relevant to the next stage in our agricultural revolution, the foremost is biotechnology.

The apprehensions relating to molecular genetics and genetic engineering fall under the following broad categories: the science itself, the control of the science, access to the science, environmental concerns, and human and animal health. A disaggregated approach to the study of these issues will be important for a rigorous analysis of risks and benefits. Dealing with these issues in a composite manner for all applications of genetic engineering will result in inappropriately broad conclusions, such as the general condemnation of GMOs expressed by non-governmental organizations (NGOs) at the World Food Summit: *five years later* held in Rome in 2002.

The benefits of molecular breeding techniques such as the use of molecular markers and undertaking precision breeding for specific characters through recombinant DNA technology are immense. The work already performed in India has revealed the potential for breeding new GM varieties possessing tolerance to salinity, drought and some major pests and diseases, together with improved nutritive quality. A new era of integrated Mendelian and molecular breeding has begun. An evergreen revolution will blend these frontier technologies with the ecological prudence of traditional communities to create technologies that are based on integrated natural resource management and that are location specific because they are developed through participatory experimentation with farm families.

This is the only way we can face the challenges of the future, particularly in the context of the growing water scarcity and the urgent need to step up productivity in semi-arid and dry farming areas. Accelerated agricultural progress is the best safety net against hunger and poverty, because in most developing countries over 70 percent of the population depend on agriculture for their livelihood. Denying ourselves the power of the new genetics will be doing a great disservice both to resource-poor farming families and to the building of a sustainable national food and nutrition system.

varieties (Evenson and Gollin, 2003). Small countries behaving rationally choose to free-ride on the international system rather than invest in large crop-breeding infrastructure of their own (Maredia, Byerlee and Eicher, 1994).

Evenson and Gollin (2003) report that, even in the 1990s, the CGIAR content of modern varieties was high for most food crops; 35 percent of all varietal releases were based on CGIAR crosses, and an additional 22 percent had a CGIAR-crossed parent or other ancestor. Evenson and Gollin suggest that germplasm contributions from international centres enabled developing countries to capture the spillover benefits of investments in crop improvement made outside their borders and achieve productivity gains that would have been more costly or even impossible had they been forced to work only with the genetic resources that were available at the beginning of the period.

Impacts of food-crop improvement technology

Substantial empirical evidence exists on the production, productivity, income and human welfare impacts of modern agricultural science and the international flow of modern varieties of food crops. Evenson and Gollin (2003) provide detailed information on the extent of adoption and impact of modern variety use for all the major food crops. The adoption of modern varieties (averaged across all crops) increased rapidly during the two decades of the Green Revolution, and even more rapidly in the following decades, from 9 percent in 1970 to 29 percent in 1980, 46 percent in 1990 and 63 percent by 1998. Moreover, in many areas and in many crops, first-generation modern varieties have been replaced by second- and third-generation modern varieties (Evenson and Gollin, 2003).

Much of the increase in agricultural output over the past 40 years has come from an increase in yield per hectare rather than an expansion of area under cultivation. For instance, FAO data indicate that for all developing countries, wheat yields rose 208 percent from 1960 to 2000; rice yields rose 109 percent; maize yields rose 157 percent; potato yields rose 78 percent and cassava yields rose 36 percent (FAO, 2003). Trends in total factor productivity are consistent with partial productivity measures, such as rate of yield growth (Pingali and Heisey, 2001).

The returns to investments in high-yielding modern germplasm have been measured in great detail by several economists over the last few decades. Several recent reports have reviewed and analysed the data from hundreds of studies conducted over the last 30 years that calculated the social rates of return to investments in agricultural research. These studies examined investments by national and international public-sector institutions in Africa, Asia, Latin America and the Organisation for Economic Co-operation and Development (OECD) countries as well as by the private sector (Alston *et al*., 2000; Evenson and Gollin, 2003). Although these studies were carried out using a variety of different methods, they showed considerable consistency. The average social rate of return to public investment in agricultural research reported in these studies is in the region of 40–50 percent. Private-sector research was also found to generate similar rates of social returns.

The primary effect of agricultural research on the non-farm poor, as well as on the rural poor who are net purchasers of food, is through lower food prices. The wide-spread adoption of modern seed-fertilizer technology led to a significant shift in the food supply function, increasing output and contributing to a fall in real food prices:

> *The effect of agricultural research on improving the purchasing power of the poor – both by raising their incomes and by lowering the prices of staple food products – is probably the major source of nutritional gains associated with agricultural research. Only the poor go hungry. Because a relatively high proportion of any income gains made by the poor is spent on food, the income effects of research-induced supply shifts can have major nutritional implications, particularly if those shifts result from technologies aimed at the poorest producers.*
>
> (Alston, Norton and Pardey, 1995: 85)

Studies by economists have provided empirical support for the proposition that growth in the agriculture sector has economy-wide effects. Hayami *et al*. (1978) illustrated at the village level that rapid growth in rice production stimulated demand and prices for land, labour and non-agricultural goods and services. For sector-level validation of the proposition that agriculture does indeed act as an engine of overall economic growth, see Hazell and Haggblade (1993); Delgado, Hopkins and Kelly (1998); and Fan, Hazell and Thorat (1998).

Once modern varieties have been adopted, the next set of technologies that makes a significant difference in reducing production costs includes machinery, land management practices (often in association with herbicide use), fertilizer use, integrated pest management and (most recently) improved water management practices. Although many Green Revolution technologies were developed and extended in package form (e.g. new plant varieties plus recommended fertilizer, pesticide and herbicide rates, along with water control measures), many components of these technologies were taken up in a piecemeal, often stepwise manner (Byerlee and Hesse de Polanco, 1986). The sequence of adoption is determined by factor scarcities and the potential cost savings achieved. Herdt (1987) provided a detailed assessment of the sequential adoption of crop management technologies for rice in the Philippines. Traxler and Byerlee (1992) provided similar evidence on the sequential adoption of crop management technologies for wheat in Sonora, northwestern Mexico.

Although the favourable, high-potential environments gained the most from the Green Revolution in terms of productivity growth, the less favourable environments also benefited through technology spillovers and through labour migration to more productive environments. According to David and Otsuka (1994), wage equalization across favourable and unfavourable environments was one of the primary means of redistributing the gains of technological change. Renkow (1993) found similar results for wheat grown in high- and low-potential environments in Pakistan. Byerlee and Moya (1993), in their global assessment of the adoption of modern varieties of wheat, found that over time the adoption of modern varieties in unfavourable environments caught up with those in more favourable environments, particularly when germplasm developed for high-potential environments was further adapted to the more marginal environments. In the case of wheat, the rate of growth in yield potential in drought-prone environments was around 2.5 percent per year during the 1980s and 1990s (Lantican and Pingali, 2003). Initially, the growth in yield potential for the marginal environments came from technological spillovers as varieties bred for the high-potential environments were adapted to the marginal environments. During the 1990s, however, further gains in yield potential came from breeding efforts targeted specifically at the marginal environments.

The Gene Revolution: a changing paradigm for agricultural R&D

In the 1960s, 1970s and 1980s, private-sector investment in plant improvement research was limited, particularly in the developing world, owing to the lack of effective mechanisms for proprietary protection of the improved products (Box 12). This situation changed in the 1990s with the emergence of hybrids for cross-pollinated crops such as maize. The economic viability of hybrids led to a budding seed industry in the developing world, started by transnational companies from the developed world and followed by the development of national companies (Morris, 1998). Despite the rapid growth of the seed industry in developing countries, its activity has been limited to date, leaving many markets underserved.

The incentives for private-sector agricultural research increased further when the United States and other industrialized countries permitted the patenting of artificially constructed genes and genetically modified plants. These national protections were strengthened by the 1995 Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organization (WTO), which obliges WTO members to provide patent protection for biotechnology inventions (products or processes) and protection for plant varieties either through patents or a *sui generis* system. These proprietary protections provided the incentives for private sector entry in agricultural biotechnology research (Box 12).

The large transnational agrochemical companies were the early investors in the development of transgenic crops, although much of the basic scientific research that paved the way was conducted by the public sector and made available to private companies through exclusive licences. One of the reasons why agrochemical companies moved into transgenic crop research and development was that they foresaw a declining market for pesticides and were looking for new products (Conway, 2000).

The chemical companies moved quickly into plant improvement by purchasing existing seed companies, first in industrialized countries and then in the developing world. These mergers between national seed companies and multinational corporations made economic sense because the two specialize in different aspects of the seed variety development and delivery process (Pingali and Traxler, 2002). This process is a continuum that starts upstream with generating knowledge on useful genes (genomics) and engineering transgenic plants and then moves downstream to the more adaptive process of backcrossing the transgenes into commercial lines and delivering the seed to farmers. The products from upstream activities have worldwide applicability across several crops and agro-ecological environments. By contrast, genetically modified crops and varieties are typically applicable to specific agro-ecological niches. In other words, spillover benefits and scale economies decline in the move to the more adaptive end of the continuum. Similarly, research costs and research sophistication decline in the

BOX 12
Public goods and intellectual property rights

Public goods are those that generate benefits for society beyond the private returns that can be captured by the person who created them. These benefits are sometimes called spillovers. Public goods are non-rival and non-excludable. Non-rivalry implies that the good is equally available to all, i.e. consumption by one person does not reduce the amount that is available for others to consume. Non-excludability means that people who do not pay for the product cannot be prevented from using it. These characteristics mean that private innovators cannot capture the full social benefit of their creation unless some means can be found to prevent unauthorized use. Because private firms cannot profit fully from research that produces public goods, they will not invest in a socially optimal level of research (Ruttan, 2001).

Much of the output of agricultural research, including biotechnology research, has one or both of the characteristics of a public good. For example, any scientist can use knowledge about the structure of the rice genome without reducing the amount of knowledge available to other scientists, and once that knowledge is published in an academic journal or on the Web, it is difficult to exclude other people from using it. A transgenic plant variety, on the other hand, may have public good characteristics to some degree (e.g. it is difficult to exclude unauthorized users completely) but it is not a pure public good because seeds can be used up and unauthorized use can be at least partially prevented.

There are two ways to prevent the unauthorized use of plant varieties – biological and legal. Hybrid seeds can be saved, reproduced and replanted but only at a significant loss in yield and quality, so hybridization provides a biological protection for the breeder's innovation. Genetic use-restriction technologies are another form of biological intellectual property protection that has been proposed for transgenic crops. These technologies would produce sterile seeds or seeds that require the application of a special chemical to activate the innovative trait. Public opposition to the sterile-seed approach has led the private company Monsanto to abandon its development. Legal protection such as patents, trademarks and contracts can also be used to protect intellectual property, but these methods usually provide incomplete protection.

progression towards downstream activities. Thus, a clear division of responsibilities in the development and delivery of biotechnology products has emerged, with the transnational firm providing the upstream biotechnology research and the local firm providing crop varieties with commercially desirable agronomic backgrounds (Pingali and Traxler, 2002).

The options available for capturing the spillovers from global corporations are less clear for public research systems. Public-sector research programmes are generally established to conform to state or national political boundaries, and direct country-to-country transfer of technologies has been limited (Pingali and Traxler, 2002). Strict adherence to political domains severely curtails spillover benefits of technological innovations across similar agroclimatic zones. The operation of the CGIAR germplasm exchange system has mitigated the problem for several important crops, but it is not clear whether the system will work for biotechnology products and transgenic crops, given the proprietary nature of the technology.

Biotechnology research investments

To understand the magnitude of private-sector investment in agricultural biotechnology research today, one need only look at its annual research budget relative to public research targeted at developing country agriculture (Pray and Naseem, 2003a). The world's top ten transnational

TABLE 3
Estimated crop biotechnology research expenditures

	(Million $/year)	*(Percentage)*
	Biotechnology R&D	**Biotechnology as share of sector R&D**
INDUSTRIALIZED COUNTRIES	**1 900–2 500**	
Private sector[1]	1 000–1 500	40
Public sector	900–1 000	16
DEVELOPING COUNTRIES	**165–250**	
Public (own resources)	100–150	5–10
Public (foreign aid)	40–50	…
CGIAR centres	25–50	8
Private sector	…	…
WORLD TOTAL	**2 065–2 730**	

[1] Includes an unknown amount of R&D for developing countries.
Source: Byerlee and Fischer, 2001.

bioscience corporations' collective annual expenditure on agricultural biotechnology research and development is nearly $3 billion. By comparison, the CGIAR, which is the largest international public-sector supplier of agricultural technologies, has a total annual budget of less than $300 million for plant improvement research and development. The largest public-sector agricultural research programmes in the developing world – those of Brazil, China and India – have annual budgets of less than half a billion dollars each (Byerlee and Fischer, 2002).

Looking at agricultural biotechnology research expenditures reveals a sharp dichotomy between developed and developing countries (Table 3). Developed countries spend four times as much as developing countries on public-sector biotechnology research, even when all sources of public funds – national, donor and CGIAR centres – are counted for developing countries. Few developing countries or international public-sector institutions have the resources to create an independent source of biotechnology innovations (Byerlee and Fischer, 2002).

Comprehensive data on private-sector biotechnology research in developing countries are not available, although most research appears to be carried out by transnational companies conducting trials of their transgenic varieties. Some work is being done by local research institutes (e.g. local private sugar-cane research institutes have fairly large biotechnology research programmes in Brazil and South Africa), whereas in India several local seed companies (notably the Maharashtra Hybrid Seed Company [Mahyco]) have biotechnology research programmes. The total investment of these private efforts is unknown but it is undoubtedly less than the public sector is investing in biotechnology research in developing countries (Pray and Naseem, 2003a).

Transgenic crop research measured by field trials

Although total biotechnology research expenditures are fairly evenly divided between the public and private sectors, the production of new technologies is almost entirely in the hands of the private sector.[1] The private sector has developed all the genetically transformed crops that have been commercialized in the world to date, with the exception of those in China (see Chapter 4). The dominance of the private sector in developing GM varieties suggests

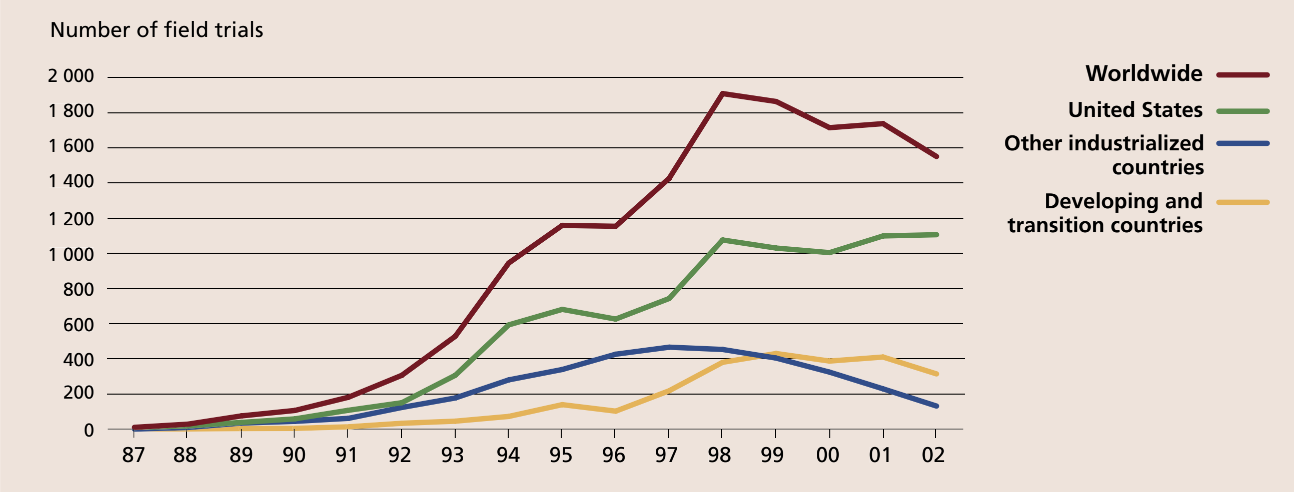
[1] Comprehensive data on field tests of all agricultural biotechnologies are not available. This section refers to transgenic crop trials only.

TABLE 4
Field trials by crop and region

	Maize	Canola	Potato	Soybean	Cotton	Tomato	Sugar beet	Tobacco	Wheat	Rice	Other	Totals
TOTAL NUMBER OF TRIALS	**3 881**	**1 242**	**1 088**	**782**	**723**	**654**	**394**	**308**	**232**	**189**	**1 610**	**11 105**
United States and Canada	2 749	826	770	552	407	494	118	194	190	102	1 087	7 489
Europe/ New Zealand/ Australia/Japan	452	366	227	20	72	89	237	61	23	36	316	1 901
Transitional economies	61	17	27	7	2	2	33	6	1	0	9	1 550
Developing countries	619	33	64	203	242	69	6	47	18	51	198	1 550
PERCENTAGE OF ALL CROPS	**35**	**11**	**10**	**7**	**7**	**6**	**4**	**3**	**2**	**2**	**14**	**100**
United States and Canada	37	11	10	7	5	7	2	3	3	1	15	100
Europe/ New Zealand/ Australia/Japan	24	19	12	1	4	5	13	3	1	2	17	100
Transitional economies	37	10	16	4	1	1	20	4	1	0	6	100
Developing countries	40	2	4	13	16	5	0	3	1	3	13	100

Source: Pray, Courtmanche and Govindasamy, 2002.

FIGURE 1
Transgenic crop field trials, by country group

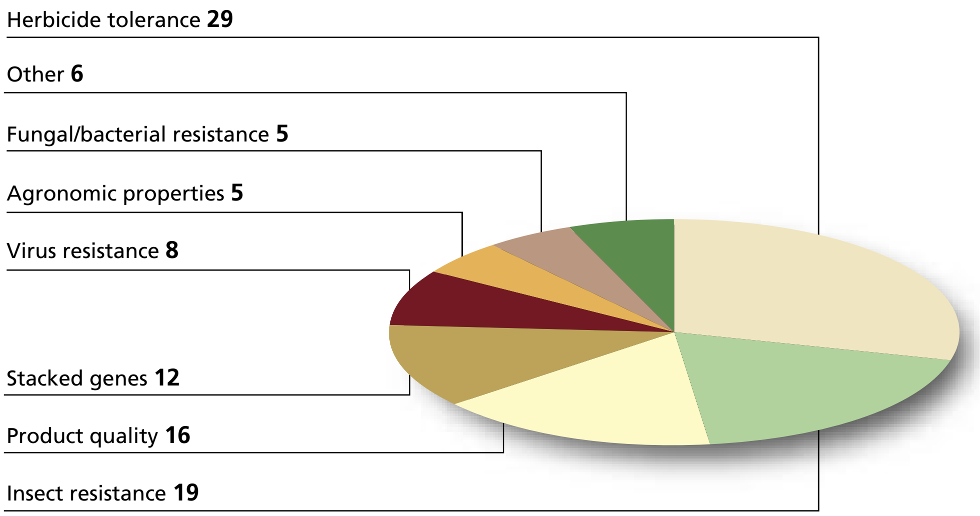


Source: Pray, Courtmanche and Govindasamy, 2002.

that the crops and production constraints of particular importance to the poor may be neglected because the markets for these seeds are probably quite small.

More than 11 000 field trials of 81 different transgenic crops have been performed since 1987 when the first trials were approved (Figure 1 and Table 4), but only 15 percent

FIGURE 2
GM crop traits tested in industrialized countries, 1987–2000 (percent)



Source: Pray, Courtmanche and Govindasamy, 2002.

have taken place in developing or transition countries.[2] This reflects the perceived lack of commercial potential in these markets and the difficulties their governments have had in establishing a regulatory system for biosafety. The number of trials in developed and transition countries has increased in recent years and at least 58 countries had reported field trials for transgenic crops by 2000 (Pray, Courtmanche and Govindasamy, 2002). Some countries have stopped field trials in certain years while re-evaluating their biosafety system.

The concern that the crops and traits of importance to developing countries could be neglected is validated by the data on field trials (Table 4, Figures 2 and 3). Staple food crops have been the subject of very little applied biotechnology research, although field trials for wheat and rice, the most important food crops in developing countries, have increased in recent years and a transgenic cassava variety was tested for the first time in 2000. Other staple food crops such as bananas, sweet potatoes, lentils and lupins have all been approved for field testing in one or more countries.

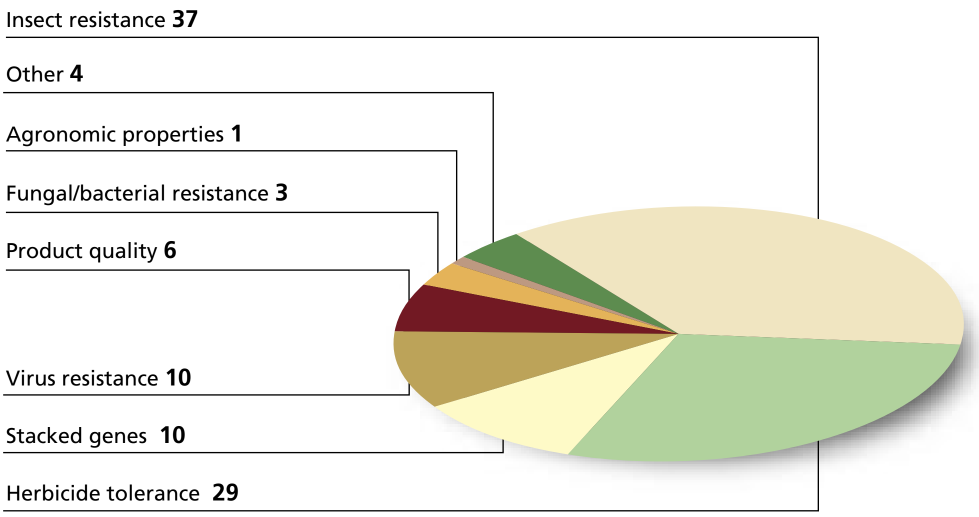
Almost two-thirds of the field trials in industrialized countries and three-quarters of those in developing countries focus on two traits: herbicide tolerance and insect resistance or a combination of the two traits together (Figures 2 and 3). Although insect resistance is an important trait for developing countries, herbicide resistance may be less relevant in areas where farm labour is abundant. By contrast, agronomic traits of particular importance to developing countries and marginal production areas, such as potential yields and abiotic stress tolerance (e.g. drought and salinity), are the subject of very few field trials in industrialized countries and even fewer in developing countries.

Transgenic crop commercialization

Transgenic crops were grown commercially in 18 countries on a total of 67.7 million ha in 2003, an increase from 2.8 million ha in 1996 (Figure 4). Although this overall rate of technology diffusion is impressive, it has been very uneven. Just six countries, four crops and two traits account for 99 percent

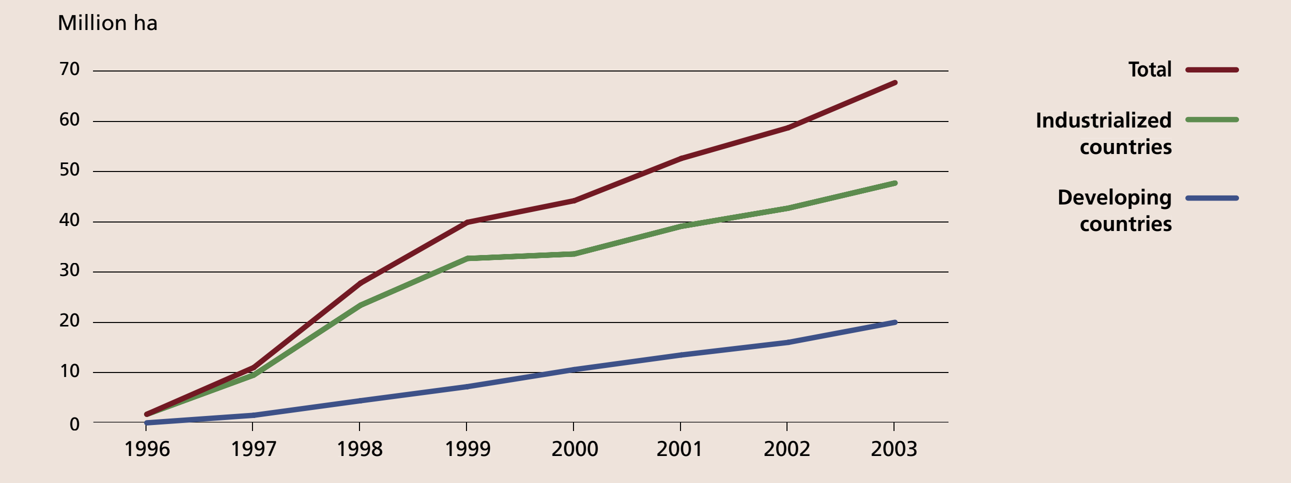
[2] This data source counts each individual test plot as a separate trial, so the same GM event may have multiple trials in a given country.

FIGURE 3
GM crop traits tested in less-developed countries, 1987–2000 (percent)



Source: Pray, Courtmanche and Govindasamy, 2002.

FIGURE 4
Global area of transgenic crops



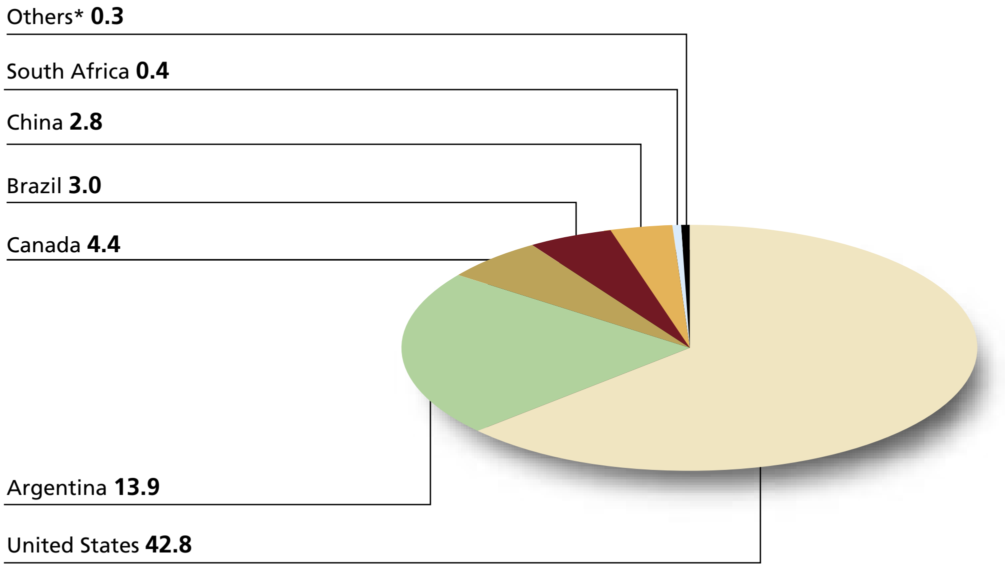
Source: James, 2003.

of global transgenic crop production (Figures 5–7) (James, 2003).

The United States plants almost two-thirds of the transgenic crops grown worldwide. Although transgenic crop area in the United States continues to expand, its share of global transgenic area has fallen rapidly as Argentina, Brazil, Canada, China and South Africa have increased their plantings. The other 12 countries where transgenic crops were grown in 2003 have a combined share of less than 1 percent of the global total.

The most widely grown transgenic crops are soybeans, maize, cotton and canola.

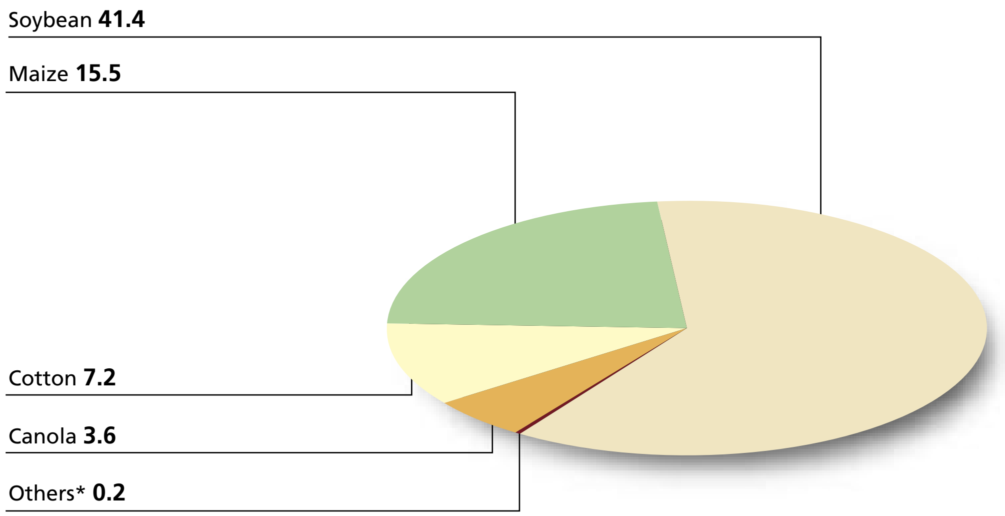
FIGURE 5
Global area of transgenic crops in 2003, by country (million ha)



* Australia, Bulgaria, Colombia, Germany, Honduras, India, Indonesia, Mexico, Philippines, Romania, Spain and Uruguay.

Source: James, 2003.

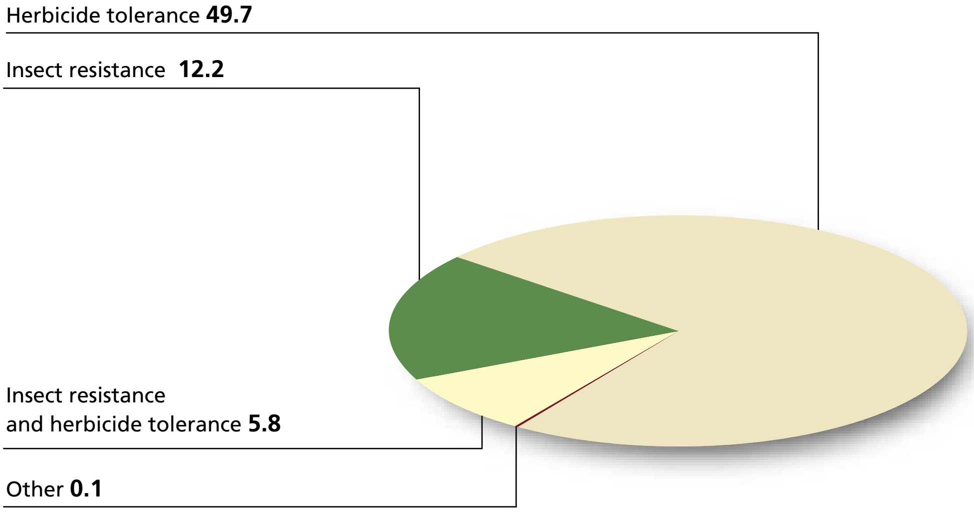
FIGURE 6
Global area of transgenic crops in 2003, by crop (million ha)



*Includes squash and papaya.

Source: James, 2003.

FIGURE 7
Global area of transgenic crops in 2003, by trait (million ha)



Source: James, 2003.

Herbicide tolerance and insect resistance are the most common traits. Herbicide-tolerant soybeans now comprise 55 percent of the global soybeans production area, and herbicide-tolerant canola comprises 16 percent of the global canola area. The transgenic cotton and maize varieties currently being grown commercially include traits for insect resistance, herbicide tolerance or both, and transgenic varieties now make up 21 percent and 11 percent, respectively, of the total area sown to those crops (James, 2003). The other transgenic crops being cultivated commercially include very small quantities of virus-resistant papaya and squash. Neither of the major food grains – wheat and rice – currently have transgenic varieties in commercial production anywhere in the world.

Conclusions

The changing locus of agricultural research from the public sector to the private transnational sector has had important implications for the types of products that are being developed and commercialized. Private-sector research naturally focuses on the crops and traits of commercial interest to farmers in higher-income countries where markets for agricultural inputs are robust and profitable. Agricultural public goods, including crops and traits of importance to subsistence farmers in marginal production environments, are of little interest to large transnational companies. Will farmers in developing countries be able to capture economic spillover benefits from the transgenic crops developed and commercialized by the private sector? What research priorities could more directly benefit the poor?

One of the lessons of the Green Revolution was that agricultural technology could be transferred internationally, especially to countries that had sufficient national agricultural research capacity to adapt the imported high-yielding cultivars to suit local production environments. What kind of research capacity do developing countries need to take advantage of the Gene Revolution? Given the dwindling resources available to public-sector research, how can more resources be mobilized for research for the poor? How can public–private partnerships be structured to capitalize on the strengths of each sector?

Unlike the high-yielding varieties disseminated in the Green Revolution, the products of the Gene Revolution are raising public concerns and encountering significant regulatory and market barriers. How do these issues influence the international transfer of new technologies? What policy measures are needed to facilitate the safe international movement of transgenic technologies?

The improved varieties that were responsible for the Green Revolution were disseminated freely as international public goods. Many of the innovations of the Gene Revolution, by contrast, are held under patents or exclusive licences. Although these intellectual property protections have greatly stimulated private-sector research in developed countries, they can restrict access to research tools for other researchers. What institutional mechanisms are needed to promote the sharing of intellectual property for public goods research?

The following section takes up these questions, examining the evidence so far regarding the economic (Chapter 4) and scientific (Chapter 5) issues surrounding transgenic crops and public concerns regarding their use (Chapter 6). The final section looks at the way forward in making biotechnology work for the poor.

4. Economic impacts of transgenic crops

Like any technological innovation in agriculture, transgenic crops will have economic impacts on farmers, consumers and society as a whole. This chapter analyses the emerging economic evidence regarding the farm-level and economy-wide impacts of the most widely adopted transgenic crop in developing countries: insect-resistant cotton. It surveys the existing peer-reviewed economic studies of the level and distribution of economic benefits derived from the adoption of insect-resistant cotton in the United States and the five developing countries where it has been approved for commercial production (Argentina, China, India, Mexico and South Africa). An additional study estimates what the economic impacts of transgenic cotton might be for farmers in five West African countries where it has not yet been approved (see Box 16 on page 55). In addition to the cotton case studies, the chapter also includes a short analysis of the economy-wide impacts of herbicide-tolerant soybeans in Argentina and the United States, the two largest growers of this crop. An *ex-ante* analysis of the potential consumer benefits of "Golden Rice" is presented in Box 13.

Sources of economic impacts

The overall economic impacts of transgenic crops will depend on a wide range of factors including, among others, the impact of the technology on agronomic practices and yields, consumers' willingness to buy foods and other products derived from transgenic crops, and regulatory requirements and associated costs. In the longer term, other factors such as industry concentration in the production and marketing of transgenic crop technology may also influence the level and distribution of economic benefits.

Farmers who adopt the new technology, especially those who adopt early, may reap benefits in terms of lower production costs and/or higher output. Other farmers could be placed at a competitive disadvantage depending on how consumer preferences and regulatory regimes evolve (see Chapter 6). If consumers are generally accepting transgenic crops and regulatory requirements are not too onerous, adopting farmers would gain and non-adopting farmers would lose. If consumer opposition grows, however, non-adopting farmers could turn that into a competitive advantage and command a price premium for non-GM products.

Consumers generally benefit from technological innovation in agriculture as a result of lower prices and/or higher quality of the products they buy. The case is more complicated with transgenic crops for at least two reasons. First, regulatory requirements such as mandatory labelling and market segregation could add to the costs of producing and marketing transgenic crops and prevent consumer prices from falling. On the other hand, some consumers are strongly opposed to the technology. These consumers could experience a welfare loss if they were

BOX 13
Projecting the economic impacts of "Golden Rice" in the Philippines

Golden Rice has been genetically engineered to produce beta-carotene, the precursor to vitamin A. Golden Rice was developed by researchers at German and Swiss universities (Ye *et al*., 2000). The owners of the patents who were involved in the development of Golden Rice have donated them for humanitarian purposes, which means that farmers in developing countries (with sales of less than $10 000) are permitted to grow and reproduce Golden Rice without paying technology fees.

Vitamin A deficiency affects more than 200 million people worldwide and is responsible for an estimated 2.8 million cases of blindness in children under five years of age (FAO, 2000a). Golden Rice has been proposed for people who depend on rice for the bulk of their diets. Critics claim that Golden Rice is an expensive, high-tech solution to a problem that should be addressed through dietary diversification and dietary supplements. Supporters agree that dietary diversification would be ideal, but argue that this goal is not attainable for the millions of people who cannot afford more than a subsistence diet. Is Golden Rice an economically efficient mechanism for delivering vitamin A to the poor?

Zimmermann and Qaim (2002) conducted the first study of the potential economic impacts of Golden Rice in the Philippines. Golden Rice is currently being adapted for local growing conditions at the Philippine-based International Rice Research Institute (IRRI). The authors estimate that the original financial effort required to develop Golden Rice was about $3 million and that a further $10 million will be required to complete adaptive research in the Philippines and to conduct the necessary safety trials. On the other hand, they estimate that Golden Rice could prevent almost 9 000 new cases of blindness and 950 deaths per year in the Philippines alone. Using a World Bank index of economic losses due to ill health and premature death, the authors calculate the potential economic benefits of Golden Rice in the Philippines at about $137 million. This represents a 10-to-1 return on the total development costs for Golden Rice and a 13-to-1 return on the marginal costs of adapting and testing the product specifically for the Philippines.

The authors acknowledge that these estimates depend on a range of parameters that are not known with certainty, such as the level of beta-carotene produced in Golden Rice, the amount of beta-carotene people will be able to absorb from it, the efficacy of the additional vitamin A in preventing disease and the number of people who would be reached by Golden Rice. Even assuming pessimistic figures for each of these factors, they estimate that Golden Rice would still yield benefits equal to more than double the costs of adapting and testing the product for the Philippine market. The authors futher report that the costs of other treatments for vitamin A deficiency in the Philippines are about $25 million per year (for food supplements and vitamin fortification) as compared with no recurrent costs for Golden Rice. They conclude that Golden Rice is a sustainable and low-cost alternative to other treatments.

forced either to consume products derived from transgenics or to buy higher priced organic products in order to avoid them.

The net economic impact of transgenic crops on society is thus a highly complex and dynamic concept that is not easily measured. In the first instance, transgenic crops will only be widely adopted if they provide economic benefits for farmers. For developing countries, in particular, a number of economic and institutional factors affect the farm-level profitability of transgenic crops in addition to their purely agronomic characteristics. Economic research is beginning to show that transgenic crops can generate farm-level benefits where they address serious production problems and where farmers have access to the new technologies. Thus far, however, these conditions are only being met in a handful of countries. These countries have been able to make use of the private-sector innovations developed for temperate crops in the North. Furthermore, these countries all have relatively well-developed national agricultural research systems, biosafety regulatory procedures, intellectual property rights regimes and local input markets. Countries lacking these prerequisites may be excluded from the gene revolution.

The existing literature on the impacts of transgenic crops in developing countries is quite limited, primarily because these crops have been grown for only a few years and in a few countries. Data for more than two or three years are rarely available, and most studies cover a relatively small number of farmers. Such small sample sizes make it particularly difficult to isolate the impact of a transgenic crop from the many other variables that influence crop performance, such as weather, seed and pesticide quality, pest loads and farmer skill. Furthermore, farmers may require several years of experience with a new technology such as insect-resistant cotton before they learn to use it efficiently. An additional problem with drawing strong conclusions from this early evidence is that early adopters of any agricultural technology tend to benefit more than later adopters. This occurs because early adopters achieve a cost advantage over other farmers, earning a premium for their innovation. As more farmers adopt the technology, the cost reduction eventually translates into a price decline for the product that means, while consumers continue to benefit, the gains to farmers decline. A third danger with transgenic crops is that they are, for the most part, controlled by a few large companies. Although these companies do not appear to be extracting monopoly profits from the sales of their products, in the absence of competition and effective regulation, there is no guarantee that they will not do so in the future.

Transgenic cotton is now being grown in a sufficiently large number of countries, under different institutional and market conditions and by different types of farmer, to allow some tentative conclusions to be drawn about the potential benefits and challenges arising from the use of transgenic crops in developing countries. Although it is risky to extrapolate results from one country or one crop to another, the early evidence for transgenic cotton suggests that resource-poor smallholders in developing countries can gain significant benefits from the adoption of transgenic crops in terms of higher and more stable effective yields, lower pesticide costs and reduced health risks from chemical pesticide exposure. Longer-term studies that carefully evaluate pest loads, crop performance, farmer behaviour and economic returns are necessary to confirm these preliminary findings. The case studies presented below indicate that the most important factors in ensuring that farmers have access to transgenic crops on favourable economic terms and under appropriate regulatory oversight include:

- sufficient national research capacity to evaluate and adapt innovations;
- active public and/or private input delivery systems;
- reliable, transparent biosafety procedures; and
- balanced intellectual property rights policies.

Global adoption of insect-resistant cotton

Transgenic cotton containing a gene from the bacterium *Bacillus thuringiensis* (Bt) that is resistant to certain insect pests (Box 14) was first grown in Australia, Mexico and the United States in 1996 and has subsequently been introduced commercially in six other countries: Argentina, China, Colombia, India, Indonesia and South Africa (Table 5). Global area planted in Bt- and stacked Bt- and herbicide-tolerant (Bt/HT) cotton varieties increased from less than 1 million ha in 1996 to 4.6 million ha in 2002 (an additional 2.2 million ha of herbicide-tolerant cotton were grown in 2002). Bt and stacked Bt/HT cotton varieties accounted for about 15 percent of global cotton area in 2002 compared with only 2 percent in 1996.

The adoption of Bt cotton has varied greatly across growing regions within China, Mexico, the United States and elsewhere depending on the particular combination of pest control problems. Bt cotton varieties

BOX 14
What is Bt cotton and why is it grown?

Genes from the common soil bacterium *Bacillus thuringiensis* (Bt) have been inserted into cotton plants, causing them to produce a protein that is toxic to certain insects. Bt cotton is highly effective in controlling caterpillar pests such as pink bollworm (*Pectinophora gossypiella*) and cotton bollworm (*Helicoverpa zea*), and is partially effective in controlling tobacco budworm (*Heliothis virescens*) and fall armyworm (*Spodoptera frugiperda*). These pests constitute a major pest control problem in many cotton-growing areas, but other cotton pests such at boll weevil are not susceptible to Bt and continue to require the use of chemical pesticides (James, 2002b). As a result, the effect of the introduction of Bt cotton on pesticide usage varies from region to region, depending on the local pest populations.

The first Bt cotton varieties were introduced commercially through a licensing agreement between the gene discoverer, Monsanto, and the leading American cotton germplasm firm, Delta and Pine Land Company (D&PL). These varieties contain the *Cry1Ac* gene and are commercialized under the trade name Bollgard®. Varieties with transgenes for insect resistance and herbicide tolerance (Bt/HT) stacked together were introduced in the United States in 1997. Monsanto recently received regulatory approval in some markets for a new product that incorporates two Bt genes, *Cry1Ac* and *Cry2Ab2*. This product, known as Bollgard II®, was commercialized in 2003. The incorporation of two Bt genes is expected to improve the effectiveness of the product and delay the development of resistant pests.

More than 35 different Bt and Bt/HT cotton varieties are on the market in the United States (data from the United States Department of Agriculture [USDA]). These varieties and most Bt varieties worldwide contain genes licensed from Monsanto. An exception is in China, where an independent source of Bt protection is available. The Chinese Academy of Agricultural Sciences (CAAS) developed a modified Bt gene that is a fusion of the *Cry1Ac* and *Cry1Ab* genes. In addition, CAAS isolated a gene from cowpea, *CpTi*, that provides insect resistance through a different mechanism. CAAS has stacked the *CpTi* gene with the Bt fusion gene and incorporated them in more than 22 locally adapted varieties for distribution in each of the Chinese provinces. The stacked CAAS varieties are expected to delay the development of resistant pests. The Monsanto *Cry1Ac* gene is also available in China through at least five varieties developed by D&PL (Pray *et al*., 2002). In Argentina, Mexico, South Africa and elsewhere, the Bt cotton varieties all contain the Monsanto *Cry1Ac* gene,

have been rapidly accepted by farmers in areas where bollworms are the primary pest problem, particularly when resistance to chemical pesticides is high. When other pest populations are high, farmers use a mixture of broad-spectrum chemicals that achieve coincidental control of bollworms, reducing the value of Bt control.

Economic impacts of transgenic cotton

The main farm-level economic impacts of the transgenic crops currently being grown are the result of changes in input use and pest damage. Where the new seeds reduce the need for chemical sprays, as can be the case with pesticide-resistant or HT crops, farmers may spend less money on chemicals and less time and effort applying them. Where the new seeds provide more effective protection from weed and pest damage, crops may have higher effective yields.[3] These cost savings and output gains can translate into higher

[3] All references to yield in this chapter refer to actual or effective yield as opposed to potential agronomic yield. Actual or effective yield accounts for losses resulting from pest damage.

often in varieties originally developed for the United States market.

Conventional cotton production relies heavily on chemical pesticides to control caterpillars and other insect pests. It is estimated that cotton production consumes about 25 percent of the agricultural pesticides used worldwide, including some of the most toxic chemicals available. Chlorinated hydrocarbons (such as DDT) were widely used in cotton production until these were banned in the 1970s and 1980s for health and environmental reasons. Cotton farmers then replaced DDT with organophosphates, many of which are also highly toxic. Pests in many regions quickly developed resistance to organophosphates, and pyrethroids, which are less toxic than organophosphates, came into widespread use in the 1980s and 1990s. Resistance to pyrethroids soon developed and multiple chemical resistance has become a severe problem in many growing regions. In areas where bollworms are the major pest and chemical resistance is a problem, Bt cotton varieties have contributed to a dramatic reduction in pesticide use.

An important advantage of Bt over chemical control of pests, from a production point of view, is that Bt control is always present in the plant. Because farmers apply chemical controls only after noticing the presence of pests on the cotton plants, some damage will have already occurred. The effectiveness of chemical insecticide applications, unlike transgenic Bt, also depends on the weather, because rain can wash the chemical away. Bt cotton offers farmers increased certainty of control because it is effective against insects that have developed resistance to available chemical pesticides. As a result, Bt varieties have superior yield performance over a wide range of growing conditions (Fernandez-Cornejo and McBride, 2000). The estimated difference in yield performance between Bt and conventional cotton varies considerably across time and space because insect infestations vary widely. The relative performance of Bt cotton is highest under conditions where pest pressure is heaviest and chemical pesticide resistance is common.

The major concern associated with the use of Bt cotton is the possibility that pests may develop resistance to Bt as they have with chemical pesticides. This would be a serious problem for organic cotton producers who rely on Bt sprays for pest control. Widespread resistance to Bt would reduce the effectiveness of this option. Pest resistance management is an important part of the regulatory approval process for transgenic cotton. This issue is discussed in more detail in Chapter 5.

net returns at the farm level. Farm-level economic gains depend on the costs and returns of the new technology compared with those of alternative practices.

The economy-wide and distributional impacts of the introduction of transgenic varieties must also take into account the fact that farmers may expand production as the new technology reduces its costs. This supply response can push prices down, benefiting consumers who may then demand more of the product. As farmers' purchases of seeds and other inputs change, prices for those items may also change, particularly if the input supplier holds a monopoly position in the market. These economy-wide forces will affect the overall level of economic benefits and the distribution of benefits among farmers, consumers and industry.

Economic impacts in the United States

In the first year of commercial availability in the United States, Bt cotton was planted on about 850 000 ha or 15 percent of the country's total cotton area. By 2001, 42 percent of the cotton area was planted to Bt and stacked Bt/HT cotton varieties (USDA-AMS, various years). The United States remains the largest producer of Bt and Bt/HT cotton, but its share of global transgenic cotton area fell from about 95 percent in 1996 to about 55 percent in 2001 as adoption in other countries increased.

United States farmers adopted Bt cotton very quickly, especially in the southern states where pest pressure is high and chemical pesticide resistance is most pronounced (Table 6). Bt cotton adoption has had a large impact on pesticide use in the United States. The average number of pesticide applications used against bollworms has fallen from 4.6 in 1992–95 to 0.8 applications in 1999–2001 (Figure 8). Carpenter and Gianessi (2001) and Gianessi *et al*. (2002) estimate that the average annual use of pesticides on cotton in the United States has been reduced by approximately 1 000 tonnes of active ingredient.

Falck-Zepeda, Traxler and Nelson (1999, 2000a, 2000b) calculated the annual impacts of Bt cotton adoption in the United States on United States cotton farmers, consumers, germplasm suppliers and foreign farmers for the 1996–98 period using a standard economic surplus model (Alston, Norton and Pardey, 1995). The estimated amount and distribution of benefits from the introduction of Bt cotton fluctuates from year to year; thus the average figures for the period 1996–98 are also shown in Figure 9. United States cotton farmers gained a total of about

TABLE 5
Bt and Bt/HT cotton area, 2001

Country	*(000 ha)* Area
United States	2 400
China	1 500
Australia	165
Mexico	28
Argentina	9
Indonesia	4
South Africa	30
Total	4 300[1]

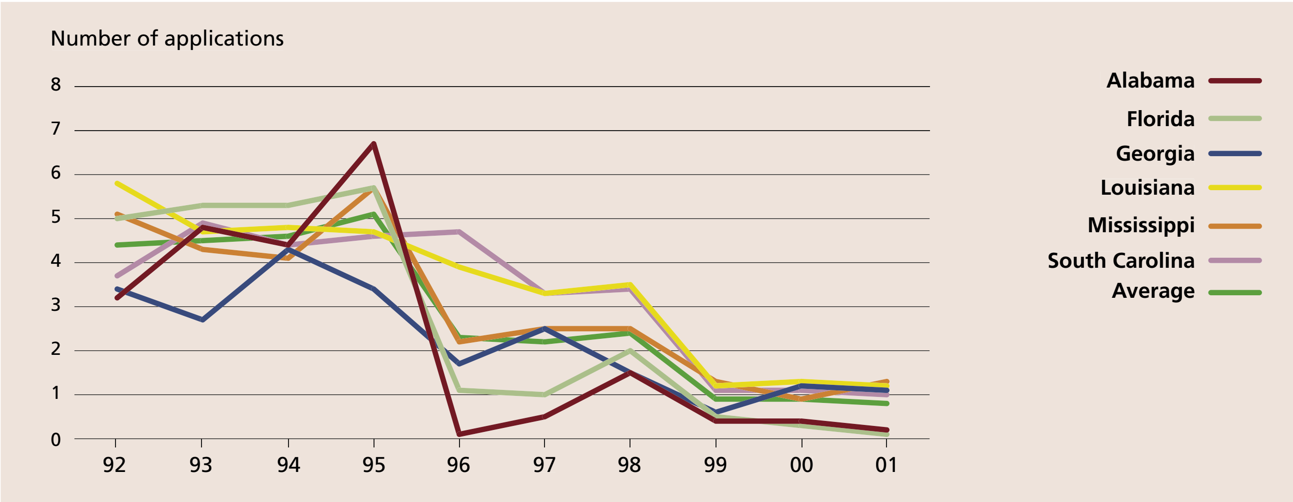
[1] Country figures do not sum to the total owing to rounding and estimates.
Source: James, 2002b.

TABLE 6
Adoption of Bt cotton by farmers in the United States by state, 1998–2001

	(Percentage)			
	1998	**1999**	**2000**	**2001**
Alabama	61	76	65	63
Arizona	57	57	56	60
Arkansas	14	21	60	60
California	5	9	6	6
Florida	80	73	75	72
Georgia	47	56	47	43
Louisiana	71	67	81	84
Mississippi	60	66	75	80
Missouri	0	2	5	22
New Mexico	38	32	39	32
North Carolina	4	45	41	52
Oklahoma	2	51	54	58
South Carolina	17	85	70	79
Tennessee	7	60	76	85
Texas	7	13	10	13
Virginia	1	17	41	30

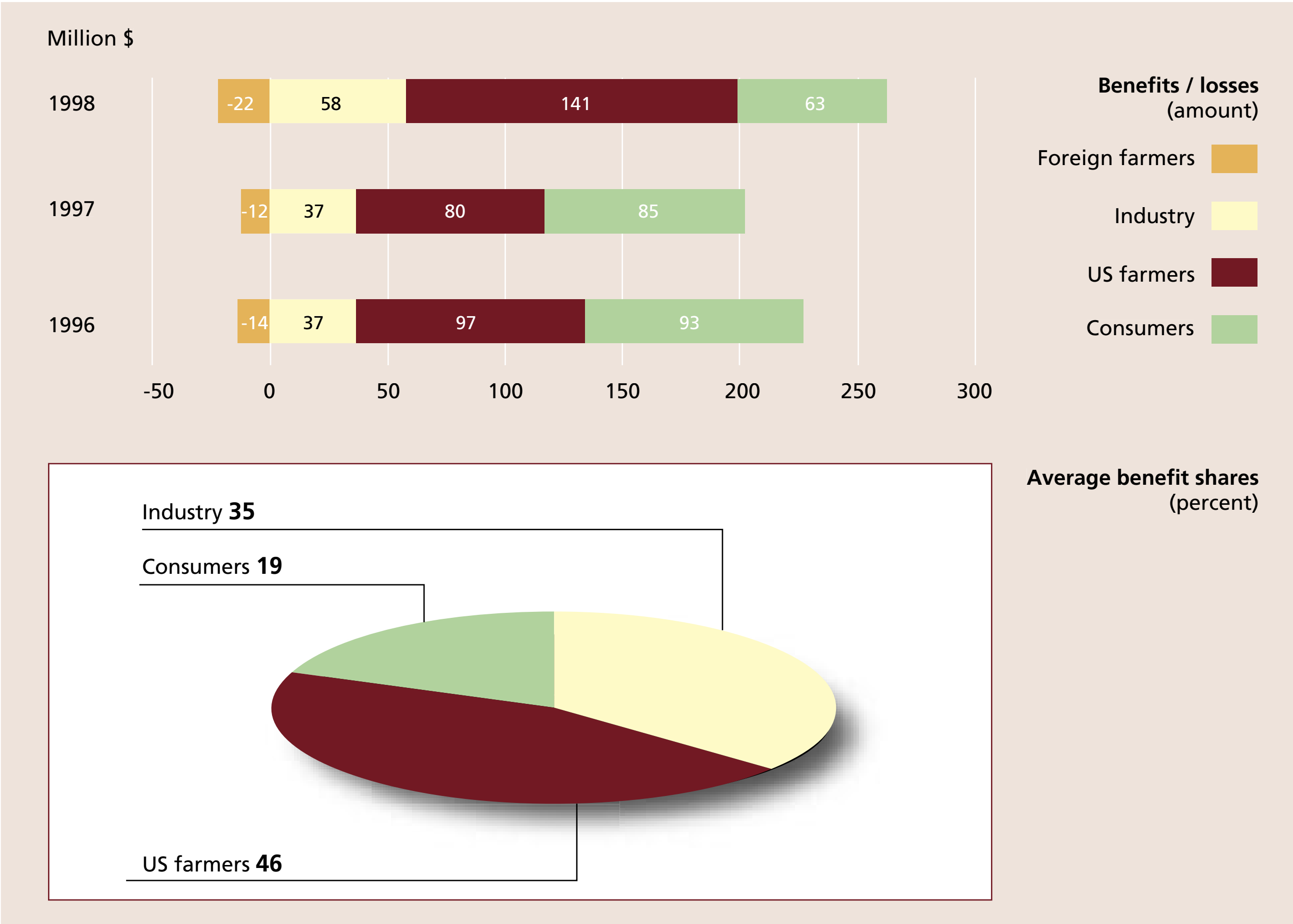
Source: USDA-AMS, various years.

FIGURE 8
Pesticide applications for budworm–bollworm complex, selected states of the United States, 1992–2001



Source: Falck-Zepeda, Traxler and Nelson, 1999.

FIGURE 9
Benefits from adopting Bt cotton in the United States, 1996–98



Source: Falck-Zepeda, Traxler and Nelson (1999, 2000a, 2000b).

TABLE 7
Performance differences between Bt and conventional cotton

	Argentina	China	India	Mexico	South Africa
LINT YIELD					
(kg/ha)	531	523	699	165	237
(Percentage)	33	19	80	11	65
CHEMICAL SPRAYS (no.)	–2.4	...	–3.0	–2.2	...
GROSS REVENUE					
($/ha)	121	262	...	248	59
(Percentage)	34	23	...	9	65
PEST CONTROL					
($/ha)	–18	–230	–30	–106	–26
(Percentage)	–47	–67	...	–77	–58
SEED COSTS					
($/ha)	87	32	...	58	14
(Percentage)	530	95	...	165	89
TOTAL COSTS					
($/ha)	99	–208	...	–47	2
(Percentage)	35	–16	...	–27	3
PROFIT					
($/ha)	23	470	...	295	65
(Percentage)	31	340	...	12	299

Sources:
Argentina: Qaim and de Janvry, 2003. Data are based on a survey of 299 farmers in two major growing provinces, averaged over two growing seasons, 1999/2000 and 2000/01.
China: Pray *et al*., 2002. Data are based on farm surveys in all cotton-growing provinces where Bt varieties were available, averaged over three growing seasons, 1999–2001. The number of Bt and non-Bt plots surveyed were 337 and 45, respectively, in 1999, 494 and 122 in 2000, and 542 and 176 in 2001.
India: Qaim and Zilberman, 2003. Data are based on field trials in seven Indian states in one growing season, 2001. The trials comprised 157 plots each of Bt cotton and a non-Bt conventional counterpart.
Mexico: Traxler *et al*., 2003. Data are based on farm surveys in the Comarca Lagunera region, averaged over two growing seasons, 1997 and 1998.
South Africa: Bennett, Morse and Ismael, 2003. Data are based on farm records and surveys in the Makhathini Flats, averaged over three growing seasons, 1998/99–2000/01. Records were examined for 1 283 farms (89 percent of all farmers in the area) in 1998/99, 441 in 1999/2000 and 499 in 2000/01.

US$105 million per year in higher net incomes as a result of Bt adoption, which lowered their production costs and raised effective yields. The industry – primarily Monsanto and D&PL – earned about US$80 million from sales of Bt technology. Increased cotton output reduced consumer prices, producing a gain of about $45 million per year for consumers in the United States and elsewhere. Farmers in other countries lost about $15 million because of lower output prices for cotton. Total net annual benefits averaged approximately $215 million. The average benefit shares were 46 percent to United States farmers, 35 percent to industry and 19 percent to cotton consumers. The loss to foreign farmers was less than 1 percent of the total net benefit generated by the adoption of Bt cotton in the United States.

Economic impacts of transgenic cotton in developing countries

Field-level studies of the performance of Bt cotton have been completed in five developing countries over periods of one to three years: Argentina (Qaim and de Janvry, 2003), China (Pray *et al*., 2002), India

(Qaim and Zilberman, 2003), Mexico (Traxler *et al*., 2003) and South Africa (Bennett, Morse and Ismael, 2003). Results from these studies are summarized in Table 7 and discussed below. Although Bt cotton varieties had higher average yields, lower pesticide use and higher net returns than their conventional counterparts in all of the developing countries where studies have been undertaken, a high degree of season-to-season and field-to-field variance is associated with the performance of both Bt and conventional cotton in these countries. Therefore, it is not possible to draw strong conclusions on the basis of two or three years of data for a few hundred farmers. Although the data so far and the continuing rapid pace of adoption suggest that farmers are benefiting from Bt cotton, it is too early to assess conclusively the level and stability of yields of Bt varieties compared with conventional varieties because these depend, among other factors, on pest infestations and agronomic practices, which vary widely.

The distributional impacts of Bt cotton have been studied for Argentina (Qaim and de Janvry, 2003), China (Pray and Huang, 2003), Mexico (Traxler *et al*., 2003) and South Africa (Kirsten and Gouse, 2003). The available evidence indicates that transgenic cotton varieties are scale neutral with regard to both speed of adoption and per hectare benefits. In other words, small farmers are equally or more likely to benefit from Bt cotton as are larger farmers. This is not surprising given the manner in which Bt cotton varieties simplify the farmers' management task. Qaim and Zilberman (2003) argue that the relative performance of Bt cotton is likely to be greatest when used by small farmers in developing countries where pest pressure is high and access to effective chemical pest control is low, because of the large pest losses typically suffered by these farmers. This notion is supported by the international data available to date, which show the yield advantage to be largest in Argentina, China and India.

Argentina

Qaim and de Janvry (2003) studied the case of Bt cotton in Argentina over two growing seasons, 1999/2000 and 2000/01. Bt cotton was first released in Argentina in 1998 by CDM Mandiyú SRL, a private joint venture between Monsanto, the Delta and Pine Land Company (D&PL) and the Argentine company Ciagro. The Bt varieties commercialized in Argentina were originally developed for the United States market. Bt cotton technology is patented in Argentina and farmers are required to pay technology fees. Under Argentine law, farmers are allowed to save and reproduce seed for one season before they are required to buy fresh certified material. However, Mandiyú requires farmers to sign special purchase contracts that prohibit the use of farm-saved seeds for Bt cotton. Unlike in other countries (or in the case of HT soybean in Argentina), the adoption of Bt cotton in Argentina has been slow and by 2001 had reached only about 5 percent of the total cotton area.

The yields for Bt cotton in Argentina averaged 531 kg/ha (or 33 percent) higher than for conventional varieties. Qaim and de Janvry (2003) note that the conventional varieties grown in Argentina are actually better adapted for local conditions and have higher agronomic potential yields than the Bt varieties, so the yield differential attributable to the reduction in pest damage to the Bt varieties would be even more than 33 percent. As there was little difference in market prices for Bt and non-Bt cotton, higher yields for the Bt varieties led to an average 34 percent increase in gross revenues. The number of pesticide applications was lower and pesticide costs were reduced almost by half. Seed costs, however, were more than six times higher for the Bt varieties than for conventional varieties and, as a result, total variable costs were 35 percent higher. Net revenues were higher for Bt than for non-Bt varieties, but by a fairly small absolute value and by a significantly smaller margin than in other countries.

Qaim and de Janvry (2003) conclude that high seed costs are the primary reason for the relatively low farm-level profit margins for Bt cotton in Argentina, which in turn explains the low rate of Bt cotton adoption compared with the rapid adoption of HT soybeans in that country (Box 15). They use a contingent valuation method to estimate that the price Argentine farmers would be willing to pay for Bt seeds is less than half of the actual price. At this lower price, farmers'

BOX 15
Herbicide-tolerant soybeans in Argentina and the United States

Genetically engineered HT crops feature a gene from the soil bacterium *Agrobacterium tumefaciens*, which makes the recipient plant tolerant to the broad-spectrum herbicide glyphosate. Introduced to a crop plant, the technology can facilitate weed management in farmers' fields. It can reduce production costs, through the substitution of glyphosate for an array of more expensive (and more toxic) herbicides. The timing and choice of herbicide is simplified for HT crops because glyphosate effectively controls both broad-leaved weeds and grasses and has a fairly broad window for the timing of application. Herbicide tolerance for various crops was developed by Monsanto under the name RoundupReady® (RR).

RR soybeans were commercially released in Argentina and the United States in 1996. The sale and use of RR technology is protected in the United States through patents and a sales contract with farmers, but neither form of intellectual property protection is used in Argentina. Thus, in Argentina, RR soybeans are widely available from sources other than Monsanto and Argentine farmers are legally allowed to use farm-saved seeds. As a result, Argentine farmers pay a relatively small price premium for RR of about 30 percent, whereas farmers in the United States on average pay 43 percent more (data from [United States] General Accounting Office, 2000). Adoption proceeded rapidly in both countries. By 2002, an estimated 99 percent of the Argentine soybean area and 75 percent of the United States area were cultivated with RR seeds (James, 2002a).

Yields of RR soybeans are not significantly different from yields of conventional soybeans in either Argentina or the United States, but reduced herbicide and tillage costs generate farm-level benefits. Many farmers switched to low-till or even no-till cultivation practices after the adoption of RR soybeans, reducing machinery and labour costs and improving soil conservation. Harvesting costs are also lower because of the lower incidence of green weeds (Qaim and Traxler, 2004).

In Argentina, the total variable cost of production is about 8 percent ($21/ha) lower for RR soybeans than for a conventional crop. Results for the United States are less clear. Moschini, Lapan and Sobolevsky (2000) estimated a cost advantage of $20/ha for 2000 for the United States as a whole, and Duffy (2001) found negligible cost savings in Iowa in 1998 and 2000. Taking an average over all sources, it appears that cost savings in the United States are similar to those in Argentina.

Qaim and Traxler (2004) estimated that RR soybeans created more than $1.2 billion in economic benefits in 2001, about 4 percent of the value of the world soybean crop. Soybean consumers worldwide gained $652 million (53 percent of total benefits) as a result of lower prices. Seed firms received $421 million (34 percent) as technology revenue,[1] most of which came from the United States market. Soybean producers in Argentina and the United States received benefits of more than $300 million and $145 million, respectively, whereas producers in countries where RR technology is not available faced losses of $291 million in 2001 as a result of the induced decline of about 2 percent ($4.06 per tonne) in world market prices. Farmers as a group received a net benefit of $158 million, 13 percent of total economic gains produced by the technology.

[1] As in the cotton studies, gross technology revenues are used as a measure of monopoly rent. No research, marketing or administration costs are deducted. If we assume, for example, that these costs amount to 33 percent of technology fee revenues, the monopoly rent would fall to around $280 million (26 percent of total surplus).

net returns would significantly increase, but company revenues would also rise because farmers would buy more seed. This finding raises an important question regarding why Mandiyú would charge prices higher than their profit-maximizing level. The authors speculate that the company may be under pressure to maintain price levels for Bt cotton technology at levels comparable with those in the United States. It also raises concerns regarding the long-term potential for private monopolies to extract excess profits from farmers in the absence of competition or appropriate regulatory constraints on monopoly power.

China

More than 4 million small farmers in China are growing Bt cotton on about 30 percent of China's total cotton area. China's share of global Bt cotton area has increased dramatically since it was first commercialized in 1997 to more than 35 percent in 2001. Pray *et al*. (2002) surveyed cotton farmers in China over three seasons from 1999 to 2001. The surveys were conducted in the main cotton-growing provinces where both Bt and non-Bt varieties were available. The initial survey included farmers in Hebei and Shandong Provinces. Adoption has advanced rapidly in these provinces because bollworms are the major pest and severe resistance to chemical pesticides is widespread. Adoption approaches 100 percent in Hebei and exceeds 80 percent in Shandong. Henan Province was added to the survey in 2000. Bt adoption has levelled off at about 30 percent in Henan despite heavy pressure from bollworms, reportedly because farmers there do not have access to the best Bt varieties. Anhui and Jiangsu Provinces were added to the study in 2001. Adoption started later and has been slower in these provinces partly because red spider mites (which are not susceptible to Bt) are a more serious problem there.

For China, the yield advantage for Bt cotton averaged 523 kg/ha or 19 percent compared with conventional varieties over the three-year period from 1999 to 2001. This translated into an average revenue gain of 23 percent. Seed costs for the Bt varieties were almost double those for conventional varieties. Compared with the Argentine case, however, this price premium is quite low. Pray *et al*. (2002) attribute the relatively low price premium for Bt seed to the presence of strong competition in the market between the CAAS varieties developed by the public sector and those available from Monsanto. Offsetting the seed price premium, pesticide costs were 67 percent lower, and total costs were 16 percent lower than for conventional cotton. Total profits averaged $470 more per hectare for the Bt producers than for the non-Bt producers, who in fact lost money in each of the three years.

Pray *et al*. (2002) estimate that Bt cotton farmers in China reduced their use of chemical pesticides by an average of 43.8 kg/ha compared with conventional cotton farmers. The largest reductions were in Hebei and Shandong Provinces, where bollworms are the major pest. Lower pesticide use translated into lower costs for chemicals and labour for spraying, but additional environmental and health benefits were also found. As a result of Bt cotton, pesticide use in China was reduced by an estimated 78 000 tonnes in 2001, an amount equal to about one-quarter of the total quantity of chemical pesticides used in China in a typical year. Because chemicals are typically applied with backpack sprayers in China and farmers rarely use protective clothing, they are often exposed to dangerous levels of pesticide. Bt cotton farmers experienced a much lower incidence of pesticide poisonings than those growing conventional varieties (5–8 percent vs 12–29 percent).

Pray and Huang (2003) looked at the distribution of economic benefits in China by farm size and income class. They found that farms of less than 1 ha had more than double the net increase in per hectare income of those larger than 1 ha (Table 8). Poorer households and individuals also received a much larger per hectare increase in net incomes than richer ones. These results suggest that Bt cotton is generating large pro-poor gains in net income in China.

India

Bt cotton was only approved for commercialization in India in 2003 and therefore market-based studies are not yet available. Qaim and Zilberman (2003) analysed Indian field trial data from 2001 and reported changes in crop yields and pesticide use between conventional and Bt cotton. The trials were initiated by the Indian

TABLE 8
Distribution of benefits of Bt cotton adoption by size of farm or income class in China, 1999

	Bt as percentage of observations	Yield increase (kg/ha)	Change in total cost ($/ha)	Change in net income ($/ha)
FARM SIZE				
0.0–0.47 ha	86	410	–162	401
0.47–1 ha	85	–134	–534	466
1+ ha	87	–124	–182	185
HOUSEHOLD INCOME (*$*)				
1–1 200	85	170	–302	380
1 200+	91	65	–54	157
PER CAPITA INCOME (*$*)				
1–180	85	456	–215	446
180–360	83	8	–284	303
360+	97	–60	1	–15

Note: all monetary figures are converted from yuan renminbi to United States dollars at the official exchange rate: $1.00 = RMB¥ 8.3.
Source: Pray and Huang, 2003.

company Maharashtra Hybrid Seed Company (Mahyco) on 395 farms in seven Indian states. The trials were supervised by regulatory authorities and managed by farmers using customary practices. The study compared yield performance and chemical use for a Bt hybrid, the same hybrid without the Bt gene, and a popular non-Bt variety grown on adjacent 646 m^2 plots. The analysis was based on results from 157 representative farms for which comprehensive records were kept. Table 7 on page 48 reports the comparison between the Bt hybrid and the same hybrid without the Bt gene.

Average effective yields for the Bt hybrid exceeded those for the non-Bt hybrid by 80 percent, reflecting high levels of pest pressure during the growing season and a lack of alternative pest control options. This yield differential is much higher than that found in China, Mexico and the United States. Qaim and Zilberman (2003) argue that the performance differential for Bt cotton is higher in India than elsewhere because pest pressure is high and farmers do not have access to affordable and effective pesticides. They argue further that the non-Bt hybrid and popular varieties had similarly poor performance, suggesting that yield potential was not a factor in the performance differential between the Bt and non-Bt hybrids. The authors acknowledge that the results for a single year may not be representative and cite data from smaller field trials conducted by Mahyco, which showed an average yield advantage of 60 percent over the four-year period 1998–2001. Other field trial studies in India have found yield advantages for Bt cotton ranging from 24 percent to 56 percent (average 39 percent) for the years 1998/99 and 2000/01 (James, 1999; Naik, 2001).

Qaim and Zilberman (2003) report that insecticide resistance is widespread in India, so that ever-increasing amounts of pesticide have to be sprayed each year. Their survey results for 2001 showed the number of chemical sprays against bollworms was reduced from an average of 3.68 to 0.62 per season, although the number of sprays against other insects was not significantly different. The overall amount of insecticide use was reduced by 69 percent, with almost all the reduction occurring in highly hazardous organophosphates, carbamates and pyrethroids belonging to international toxicity classes I and II.

TABLE 9
Adoption of Bt cotton and geographical distribution of pest problems in Mexico's major cotton-producing areas, 1997–98

Pest	Bt effectiveness	Other plant hosts	Seriousness of problem[1]					
			Comarca Lagunera	Tamaulipas	North Chihuahua	South Chihuahua	Sonora	Baja California
Pink bollworm	Total	None	Highest	None	Minor	Medium	Medium	Medium
Cotton bollworm	High	Maize, tomato	High	High	Medium	Medium	Minor	Minor
Tobacco budworm	Partial	Maize, tomato	Medium	High	Medium	Medium	Medium	Minor
Armyworm	Partial	Many	Minor	High	Medium	Medium	Minor	Minor
Boll weevil	None	None	Eradicated	Highest	Minor	Highest	Minor	None
Whitefly	None	Many	Minor	None	None	None	Highest	Highest
2000 Bt adoption *(percent)*			96	37	38	33	6	1

[1] Highest: requires multiple applications annually, potentially heavy crop damage; high: 2–3 applications required most years, some crop damage; medium: 1–2 applications required most years, minor crop damage; minor: not necessary to spray most years, some crop damage.
Source: Traxler *et al*., 2003.

Mexico

The amount of cotton planted in Mexico varies widely from year to year depending on government policies, exchange rates, world prices and – critically – the availability of water for irrigation. Cotton area declined from about 250 000 ha in the mid-1990s to about 80 000 ha in 2000, whereas the share planted to Bt varieties grew from about 5 percent to 33 percent.

Bt adoption patterns in Mexico reflect regional patterns of pest infestation and economic losses resulting from pest damage (Table 9). Adoption has been most rapid in Comarca Lagunera, a region that comprises parts of the states of Coahuila and Durango, and the region most critically affected by bollworms. The other cotton-growing regions of Mexico are afflicted with boll weevil and other pests that are not susceptible to Bt and thus require the use of chemical controls. Bt adoption is correspondingly low in these regions. Bt cotton is barred from the southern states of Chiapas and Yucatan where wild species of *Gossypium hirsutum*, a native relative of cotton, exist (Traxler *et al*., 2003).

The Bt cotton varieties grown in Mexico were developed originally for the United States market by D&PL in cooperation with Monsanto. Monsanto requires farmers in Mexico to sign a seed contract that forbids them from saving seed and requires them to have their cotton ginned only at Monsanto-authorized mills. The contract also requires farmers to follow a specified resistance management strategy and to permit Monsanto agents to inspect their fields for compliance with refugia and seed-saving restrictions (Traxler *et al*., 2003).

Cotton producers in Comarca Lagunera are generally classified as falling into one of three groups: *ejidos*, small landholders and independent producers. *Ejidos* have landholdings of 2–10 ha, small producers 30–40 ha and independent producers somewhat more but typically less than 100 ha. *Ejidos* and small landholders are organized into farmer associations for the purposes of obtaining credit and technical assistance. Each farmer group has a technical consultant who works for the association. Traxler *et al*. (2003) surveyed cotton farmers in Comarca Lagunera for the 1997 and 1998 growing seasons through the technical consultants working for the association SEREASA. The association is one of the largest in Comarca Lagunera, and had 638 farmers owning almost 5 000 ha of land during the study period. Of this total area, between 2 000 and 2 500 ha were planted to cotton, about 12 percent of the cotton area in Comarca Lagunera. Bt varieties were planted on 52 percent of the cotton area in Comarca

TABLE 10
Estimates of economic benefit distribution, Comarca Lagunera region of Mexico, 1997 and 1998

		1997	1998	Average
A	Cost per hectare to produce Bt seed *($)*	30.94	30.94	30.94
B	Monsanto/D&PL Bt revenue per hectare *($)*	101.03	86.60	93.82
C = B – A	Monsanto/D&PL net revenue per hectare[1] *($)*	70.09	55.66	62.88
D	Change in farm profit per hectare *($)*	7.74	582.01	294.88
E	Bt area in Comarca Lagunera *(ha)*	4 500	8 000	6 250
F = C × E	Monsanto/D&PL total net revenue[1] *($)*	315 405	445 280	380 342
G = D × E	Total farmer benefits *($)*	34 830	4 656 080	2 345 455
H = F + G	Total benefits[1] produced *($)*	350 235	5 101 360	2 725 798
I = F/H	Monsanto/D&PL share of total benefits[1] *(percent)*	90	9	14
J = G/H	Producer share of total benefits *(percent)*	10	91	86

[1] Monsanto/D&PL net revenue calculated before administrative and sales expenses and before any compensation to Mexican seed distribution agents.
Source: Traxler *et al*., 2003.

Lagunera in 1997, increasing to 72 percent in 1998. According to the authors, the sample group was fairly representative of small-to-medium landholders but probably underrepresented large producers.

The average effective yield differential between Bt and conventional cotton was 165 kg/ha or about 11 percent, considerably lower than for the other countries shown in Table 7. The yield differential varied sharply over the two growing seasons covered by the survey, from almost nil in 1997 to 20 percent in 1998. The authors noted that 1997 was a year of very low pest pressure in Comarca Lagunera. Pesticide costs were about 77 percent lower for Bt than for conventional cotton, and the number of chemical sprays was lower. Seed costs were almost three times higher for Bt cotton, reflecting a fairly high technology premium. As a result, the average profit differential for the two years was $295/ha. This varied from less than $8 in 1997 to $582 in 1998.

Traxler *et al*. (2003) calculated the distribution of the economic benefits from Bt cotton in Comarca Lagunera between the farmers in the region and the companies supplying the Bt varieties, Monsanto and D&PL. For the two years of the study, farmers captured an average of 86 percent of the total benefits, compared with 14 percent for the germplasm suppliers (Table 10). The per hectare change in profit accruing to farmers varied widely between the two years, as noted above. As a result, the total producer surplus ranged from less than $35 000 to almost $5 million. For the two years, an estimated total of almost $5.5 million in benefits was produced, most of it in the second year and most of it captured by farmers. In this calculation the entire amount attributed to Monsanto and D&PL cannot be considered truly a net benefit to the companies, because costs such as seed distribution, administration and marketing costs were not accounted for. A revenue of $1.5 million from seed sales is not a large sum for a company like Monsanto, which has $5.49 billion in annual revenue. The large annual fluctuations are largely caused by variability in pest infestation levels; in years of heavy pest pressure, Bt cotton produces a large advantage over conventional cotton varieties. Because Mexico grows a small share of the world's cotton, there are no economy-wide effects on prices or consumer welfare.

South Africa

Bt cotton was the first transgenic crop to be commercially released in sub-Saharan Africa following the implementation in 1999 of the Genetically Modified Organisms Act, 1997. By 2002 some 30 000 ha of Bt cotton were planted in South Africa, of which about 5 700 ha were in the Makhathini Flats area of KwaZulu-Natal Province. Bennett, Morse and

Ismael (2003) examined the experience of resource-poor smallholder cotton farmers in the Makhathini Flats.

Vunisa Cotton is a private commercial company in the Makhathini Flats that supplies farmers with cotton inputs (seed, pesticide and credit) and buys their output. Bennett, Morse and Ismael (2003) used individual farmer records held by Vunisa Cotton to collect information on input use, yields, farm characteristics and other information for the three growing seasons beginning in 1998/99. In addition, personal interviews were undertaken with a random sample of smallholder farmers in 1998/99 and 1999/2000, and 32 in-depth case study interviews were conducted in 2000/01.

The authors report that adopters of Bt cotton benefited from higher yields (as a result of less pest damage), lower pesticide use and less labour for pesticide applications. Yields were an average 264 kg/ha (65 percent) higher for the adopters. The yield differential was particularly large in the poor, wet growing season of 1999/2000, reaching 85 percent. Adopters used less seed per hectare than non-adopters, but higher prices for Bt seed meant that total seed costs were 89 percent higher. This was offset by lower pesticide and labour costs, so total costs were only 3 percent higher for Bt cotton on average. Higher yields and nearly equal costs meant that Bt adopters achieved net profits 3–4 times higher than those of conventional producers in all growing seasons, with the differential being especially large in 1999/2000, when conventional growers lost money.

The authors examined the dynamics of Bt adoption and the distribution of benefits

BOX 16

Costs of not adopting Bt cotton in West Africa

In a study of five West African cotton-producing countries, Cabanilla, Abdoulaye and Sanders (2003) examined the economic benefits that could accrue to cotton farmers if Bt cotton were introduced to the region. Cotton is a major source of export revenue in these countries – Benin, Burkina Faso, Côte d'Ivoire, Mali and Senegal – and a source of cash income for millions of resource-poor farmers. Depending on the rate of adoption and the actual yield advantage, the potential benefits for these countries as a group could range from $21 million to $205 million.

Cabanilla, Abdoulaye and Sanders (2003) based their analysis on the similarities between pest populations and chemical use in these countries with those found in other developing countries where Bt cotton has been introduced. The major insect pests in West Africa are bollworms, which are currently controlled by spraying up to seven times per season with broad-spectrum insecticides, usually a combination of organophosphates and pyrethroids. As in other regions where these insecticides are used, pest resistance has been reported. Given current conditions, the authors conclude that Bt cotton would probably be highly effective in controlling the pests found in the region.

The authors used the experiences of other developing countries to posit a range of yield increases and cost reductions that could accompany the adoption of Bt cotton. These assumptions were then used to calculate a range of potential economic impacts for the five countries under alternative adoption scenarios. Under their most optimistic scenario (45 percent yield advantage and 100 percent adoption) farmers in the five countries would earn an additional $205 million in net revenues: Mali $67 million, Burkina Faso $41 million, Benin $52 million, Côte d'Ivoire $38 million and Senegal $7 million. Under the most pessimistic scenario (10 percent yield advantage and 30 percent adoption) total benefits are reduced to $21 million, allocated proportionately among the five countries as in the first scenario. These results translate into farm-level income gains per hectare of 50–200 percent.

In 2003, the Government of Burkina Faso embarked on the evaluation of Bt cotton in cooperation with Monsanto.

across farm size. In 1997/98, Vunisa Cotton purposely targeted the release of Bt cotton to a few, relatively large, farmers. By 1998/99, the first growing season of this study, approximately 10 percent of smallholders in Makhathini had adopted Bt cotton, followed by 25 percent the second year and 50 percent the third year. By the fourth season, 2001/02, which was not covered in the analysis because of data limitations, an estimated 92 percent of smallholder cotton farmers in the region had adopted the Bt variety. The authors report that larger, older, male and wealthier farmers were more likely to adopt in the first season, but by the second and third seasons, smaller farmers of various ages and both genders were also growing Bt cotton. Their analysis showed that smaller farmers growing Bt cotton actually earned higher per hectare gross margins than did larger Bt cotton growers.

Conclusions

This chapter has reviewed the experience to date with the use of transgenic crop varieties, especially Bt cotton, in developing countries. The evidence has been collected from impact studies of the diffusion of Bt cotton in Argentina, China, India, Mexico and South Africa, as well as in the United States. Additional evidence on the impact of HT soybeans in Argentina and the United States was also discussed. Some general conclusions emerge from the review of these crops, although caution is necessary in extrapolating from one crop or country to another, from the short term to the long term and from a small sample of farmers to an entire sector.

First, transgenic crops have delivered large economic benefits to farmers in some areas of the world over the past seven years. In several cases the per hectare savings, particularly from Bt cotton, have been large when compared with almost any other technological innovation introduced over the past few decades. However, even within those countries where transgenic products have been available, adoption rates have varied greatly across production environments depending on the specific production challenges present in the area and the availability of suitable cultivars. Transgenic crops can be useful in certain circumstances, but they are not the solution to all problems.

Second, the availability of suitable transgenic cultivars often depends on national research capacities, and their accessibility by small farmers always depends on the existence of an effective input delivery system. Farmers in some countries have been able to take advantage of innovations and crop varieties developed for the North American market, but for most parts of the world the development of locally adapted ecology-specific cultivars will be essential. In all countries where transgenic cotton has been adopted by small farmers, a seed delivery mechanism has been in place and in some cases small farmers have been specifically targeted. In most countries, national seed companies have served this function in cooperation with a transnational firm and, often, with the support of the national government and farmers' organizations.

Third, the economic impacts of Bt cotton depend on the regulatory setting in which it is introduced. In all the cases studied, the countries have a biosafety process in place that has approved the commercial planting of Bt cotton. Countries that lack biosafety protocols or the capacity to implement them in a transparent, predictable and trusted way may not have access to the new technologies. A related concern is that farmers in some countries may be planting transgenic crops that have not been evaluated and approved through proper national biosafety procedures. These crops may have been approved in a neighbouring country or they may be unauthorized varieties of an approved crop. Where the crop has not been cleared through a biosafety risk assessment that takes into consideration local agro-ecological conditions, there may be a greater risk of harmful environmental consequences (see Chapter 5). Furthermore, unauthorized varieties may not provide farmers with the expected level of pest control, leading to continued need for chemical pesticides and a greater risk of the development of pest resistance (Pemsl, Waibel and Gutierrez, 2003).

Fourth, although the transgenic crops have been delivered through the private sector in most cases, the benefits have been widely distributed among industry, farmers and final consumers. This suggests that the monopoly position engendered by intellectual property protection does not automatically lead to excessive industry profits. It is apparent from the Bt cotton results for Argentina, however, that the balance between the intellectual property rights of technology suppliers and the financial means of farmers has a crucial impact on adoption of the products and hence on the level and distribution of benefits. The case of China clearly illustrates that public-sector involvement in research and development and in the delivery of transgenic cotton can help ensure that poor farmers have access to the new technologies and that their share of the economic benefits is adequate.

Fifth, the environmental effects of Bt cotton have been strongly positive. In virtually all instances insecticide use on Bt cotton is significantly lower than on conventional varieties. Furthermore, for HT soybeans, glyphosate has been substituted for more toxic and persistent herbicides, and reduced tillage has accompanied HT soybeans and cotton in many cases. Negative environmental consequences, although meriting continued monitoring, have not been documented in any setting where transgenic crops have been deployed to date.

Finally, evidence from China (Pray and Huang, 2003), Argentina (Qaim and de Janvry, 2003), Mexico (Traxler *et al*., 2003) and South Africa (Bennett, Morse and Ismael, 2003) suggests that small farmers have had no more difficulty than larger farmers in adopting the new technologies. In some cases, transgenic crops seem to simplify the management process in ways that favour smaller farmers.

The question therefore is not whether biotechnology is capable of benefiting small resource-poor farmers, but rather how this scientific potential can be brought to bear on the agricultural problems of developing country farmers. Biotechnology holds great promise as a new tool in the scientific toolkit for generating applied agricultural technologies. The challenge at present is to design an innovation system that focuses this potential on the problems of developing countries.

5. Health and environmental impacts of transgenic crops

The scientific evidence concerning the environmental and health impacts of genetic engineering is still emerging. This chapter briefly summarizes the current state of scientific knowledge on the potential health and environmental risks (Box 17) associated with genetic engineering in food and agriculture, followed by a discussion of the role of international standard-setting bodies in harmonizing risk analysis procedures for these products (Box 18). The scientific evidence presented in this chapter relies largely on a recent report from the International Council for Science (ICSU, 2003 – referred to hereafter as ICSU).[4] The ICSU report draws on 50 independent scientific assessments carried out by authoritative groups in different parts of the world, including the FAO/WHO Codex Alimentarius Commission, the European Commission, the OECD and the national science academies of many countries such as Australia, Brazil, China, France, India, the United Kingdom and the United States. In addition, this chapter draws on recent scientific evaluations from the Nuffield Council on Bioethics (2003 – referred to hereafter as Nuffield Council),[5] the United Kingdom GM Science Review Panel (2003 – referred to hereafter as GM Science Review Panel)[6] and the Royal Society (2003 – referred to hereafter as Royal Society)[7] that were not available when the ICSU report was prepared. There is a substantial degree of consensus within the scientific community on many of the major safety questions concerning transgenic products, but scientists disagree on some issues, and gaps in knowledge remain.

Food safety implications

Currently available transgenic crops and foods derived from them have been judged safe to eat and the methods used to test their safety have been deemed appropriate. These conclusions represent the consensus of the scientific evidence surveyed by the ICSU (2003) and they are consistent with the views of the World Health Organization (WHO, 2002). These foods have been assessed for increased risks to human health by several national regulatory authorities (*inter alia*, Argentina, Brazil, Canada, China, the United Kingdom and the United States) using their national food safety procedures (ICSU). To date no verifiable untoward toxic or nutritionally deleterious effects resulting from the consumption of foods derived from genetically modified crops have been discovered anywhere in the world (GM Science Review Panel). Many millions of people have consumed foods derived from GM plants – mainly maize, soybean and oilseed rape – without any observed adverse effects (ICSU).

The lack of evidence of negative effects, however, does not mean that new transgenic foods are without risk (ICSU, GM Science Review Panel). Scientists acknowledge that not enough is known about the long-term effects of transgenic (and most traditional) foods. It will be difficult to detect long-term

[4] The International Council for Science (ICSU) is a non-governmental organization representing the international scientific community. The membership includes both national science academies (101 members) and international scientific unions (27 members). Because the ICSU is in contact with hundreds of thousands of scientists worldwide, it is often called upon to represent the world scientific community.

[5] The Nuffield Council on Bioethics is a British non-profit organization funded by the Medical Research Council, the Nuffield Foundation and the Wellcome Trust.

[6] The GM Science Review Panel is a group established by the United Kingdom Government to conduct a thorough, impartial review of the scientific evidence regarding GM crops.

[7] The Royal Society is the independent scientific academy of the United Kingdom, dedicated to promoting excellence in science.

BOX 17
The nature of risk and risk analysis

Risk is an integral part of everyday life. No activity is without risk. In some cases inaction also entails risk. Agriculture in any form poses risks to farmers, consumers and the environment. Risk analysis consists of three steps: risk assessment, risk management and risk communication. Risk assessment evaluates and compares the scientific evidence regarding the risks associated with alternative activities. Risk management – which develops strategies to prevent and control risks within acceptable limits – relies on risk assessment and takes into consideration various factors such as social values and economics. Risk communication involves an ongoing dialogue between regulators and the public about risk and options to manage risk so that appropriate decisions can be made.

Risk is often defined as "the probability of harm". A hazard, by contrast, is anything that might conceivably go wrong. A hazard does not in itself constitute a risk. Thus assessing risk involves answering the following three questions: What might go wrong? How likely is it to happen? What are the consequences? The risk associated with any action depends on all three elements of the equation:

Risk = hazard × probability × consequences.

The seemingly simple concept of risk assessment is in fact quite complex and relies on judgement in addition to science. Risk can be underestimated if some hazards are not identified and properly characterized, if the probability of the hazard occurring is greater than expected or if its consequences are more severe than expected. The probability associated with a hazard also depends, in part, on the management strategy used to control it.

In daily life, risk means different things to different people, depending on their social, cultural and economic backgrounds. People who are struggling to survive may be willing to accept more risk than people who are comfortably well-off, if they believe it carries a chance of a better life. On the other hand, many poor farmers choose only low-risk technologies because they are functioning at the margins of survival and cannot afford to take chances. Risk also means different things to the same person at different times, depending on the particular issue and the particular situation. People are more likely to accept the risks associated with familiar and freely chosen activities, even if the risks are large. In risk analysis, the following questions should be kept in mind: Who bears the risk and who stands to benefit? Who evaluates the harm? Who decides what risks are acceptable?

effects because of many confounding factors such as the underlying genetic variability in foods and problems in assessing the impacts of whole foods. Furthermore, newer, more complex genetically transformed foods may be more difficult to assess and may increase the possibility of unintended effects. New profiling or "fingerprinting" tools may be useful in testing whole foods for unintended changes in composition (ICSU).

The main food safety concerns associated with transgenic products and foods derived from them relate to the possibility of increased allergens, toxins or other harmful compounds; horizontal gene transfer particularly of antibiotic-resistant genes; and other unintended effects (FAO/WHO, 2000). Many of these concerns also apply to crop varieties developed using conventional breeding methods and grown under traditional farming practices (ICSU). In addition to these concerns, there are direct and indirect health benefits associated with transgenic foods that should be more fully evaluated.

Allergens and toxins

Gene technology – like traditional breeding – may increase or decrease levels of naturally occurring proteins, toxins or other harmful compounds in foods. Traditionally developed foods are not

BOX 18
International standards to facilitate trade

Opportunities for agricultural trade have increased dramatically over the past several years as a result of reforms in international trade under the World Trade Organization (WTO). To a large extent, these reforms centred on reducing tariffs and subsidies in various sectors. The Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) was also adopted under the WTO in 1994 and entered into force in 1995. The SPS Agreement establishes that countries retain their right to ensure that the food, animal and plant products they import are safe, and at the same time it states that countries should not use unnecessarily stringent measures as disguised barriers to trade.

The SPS Agreement concerns in particular: the protection of animal or plant life or health arising from the entry, establishment or spread of pests, diseases, disease-carrying organisms or disease-causing organisms; the protection of human or animal life or health from risks arising from additives, contaminants, toxins or disease-causing organisms in foods, beverages or feedstuffs; the protection of human life or health from risks arising from diseases carried by animals, plants or products thereof, or from the entry, establishment or spread of pests; and the prevention or limitation of other damage from the entry, establishment or spread of pests.

The SPS Agreement states that countries should use internationally agreed standards in establishing their requirements for sanitary and phytosanitary measures. To meet this objective, three international standard-setting bodies are identified: the Codex Alimentarius Commission for food safety, the International Office of Epizootics (OIE)[1] for animal health and the IPPC for plant health. By using standards, countries can reach the level of protection needed to protect human, animal or plant life or health. Countries may also adopt measures that differ from standards, but in these cases, the measures should be technically justified and based on risk assessment.

[1] Since renamed the World Organisation for Animal Health, although the acronym OIE has been retained.

generally tested for these substances even though they often occur naturally and can be affected by traditional breeding. The use of genes from known allergenic sources in transformation experiments is discouraged and if a transformed product is found to pose an increased risk of allergenicity it should be discontinued. The GM foods currently on the market have been tested for increased levels of known allergens and toxins and none has been found (ICSU). Scientists agree that these standard tests should be continuously evaluated and improved and that caution should be exercised when assessing all new foods, including those derived from transgenic crops (ICSU, GM Science Review Panel).

Antibiotic resistance

Horizontal gene transfer and antibiotic resistance is a food safety concern because many first-generation GM crops were created using antibiotic-resistant marker genes. If these genes could be transferred from a food product into the cells of the body or to bacteria in the gastrointestinal tract this could lead to the development of antibiotic-resistant strains of bacteria, with adverse health consequences. Although scientists believe the probability of transfer is extremely low (GM Science Review Panel), the use of antibiotic-resistant genes has been discouraged by an FAO and WHO expert panel (2000) and other bodies. Researchers have developed methods to eliminate antibiotic-resistant markers from genetically engineered plants (Box 20).

Other unintended changes

Other unintended changes in food composition can occur during genetic improvement by traditional breeding and/or gene technology. Chemical analysis is used

BOX 19
Health and environmental concerns in conventional plant breeding

Prior to the advent of genetic engineering, plant breeding was not subject to a great deal of regulation. Seed certification standards ensure the purity and quality of seeds, but little attention has been paid to the possible food safety or environmental impacts of new plant varieties derived from conventional breeding.

Conventional plant breeding differs considerably from natural selection. Natural selection creates resilient biological systems; it ensures the development of an organism that contains properties that adapt it to a variety of environmental conditions and ensure continuation of the species. Artificial selection and conventional plant breeding break down precisely these resilient systems, thereby creating gene combinations that would rarely survive in nature.

Conventional breeding has been responsible for a few cases of negative effects on human health. In one case a potato cultivar was found to contain excessive levels of naturally occurring toxins, and in another case a celery cultivar conventionally bred for high insect resistance caused a skin rash if harvested by hand without protection.

Similarly, the potential impacts of conventionally bred crops on the environment or on farmers' traditional varieties generally have not given rise to regulatory controls, although some of the concerns associated with genetically transformed crops are equally applicable to conventional crops. Most of the world's major food crops are not native to their major production zones; rather, they originated in a few distinct "centres of origin" and were transferred to new production areas through migration and trade. Highly domesticated plants are grown all over the world and migration outside cultivated areas has only rarely caused a serious problem. Even when grown in their centre of origin, as with potatoes in South America or maize in Mexico, hybrids between cultivated and wild species have not been permanently established. There are several reports of gene flow between cultivated plants and their wild relatives but in general this has not been considered a problem.

Source: DANIDA, 2002.

to test GM products for changes in known nutrients and toxicants in a targeted way. Scientists acknowledge that more extensive genetic modifications involving multiple transgenes may increase the likelihood of other unintended effects and may require additional testing (ICSU, GM Science Review Panel).

Potential health benefits of transgenic foods

Scientists generally agree that genetic engineering can offer direct and indirect health benefits to consumers (ICSU). Direct benefits can come from improving the nutritional quality of foods (e.g. Golden Rice), reducing the presence of toxic compounds (e.g. cassava with less cyanide) and by reducing allergens in certain foods (e.g. groundnuts and wheat). However, there is a need to demonstrate that nutritionally significant levels of vitamins and other nutrients are genetically expressed and nutritionally available in new foods and that there are no unintended effects (ICSU). Indirect health benefits can come from reduced pesticide use, lower occurrence of mycotoxins (caused by insect or disease damage), increased availability of affordable food and the removal of toxic compounds from soil. These direct and indirect benefits need to be better documented (ICSU, GM Science Review Panel).

International standards for food safety analysis

At the 26th session of the Codex Alimentarius Commission, held from 30 June

BOX 20
"Clean gene" transformation at CIMMYT

Alessandro Pellegrineschi and David Hoisington[1]

Since the introduction of GM crops, a part of civil society has expressed concern about the antibiotic- and herbicide-resistance genes used as selectable marker genes in the development of transgenic plants. They cite potential ecological and health hazards, specifically the evolution of "superweeds" from herbicide resistance and the build-up of resistance to antibiotics in human pathogens. Although most scientists believe that these concerns are largely unfounded, and neither hazard has actually materialized, the development of marker-gene-free transgenics would help defuse such concerns and could contribute to the public acceptance of transgenic crops (Zuo *et al.*, 2002).

Several methods have been reported to create transformed plants that do not carry marker genes, for example co-transformation (Stahl *et al.*, 2002), transposable elements (Rommens *et al.*, 1992), site-specific recombination (Corneille *et al.*, 2001) and intrachromosomal recombination (De Vetten *et al.*, 2003). The International Maize and Wheat Improvement Center (known by its Spanish acronym, CIMMYT) is committed to providing resource-poor farmers in developing countries with the best options for implementing sustainable maize and wheat systems. CIMMYT believes that although GM crops will not solve all of the problems faced by farmers, the technology does have great potential and should be evaluated.

Scientists at CIMMYT have developed and adapted a transformation technique for wheat and maize to produce genetically modified plants that do not carry the selectable marker genes. With this technique, two DNA fragments, one containing the selectable marker gene and the other containing the gene of interest, are introduced and integrated separately into the genome. During the selection process, these genes segregate from each other, allowing the selection of the plants with only the gene of interest. CIMMYT scientists tested this simple technique using the selectable gene *bar* and the Bt genes, *Cry1Ab* and *Cry1Ba*, and successfully obtained plants without the selectable marker gene but with the Bt gene and which expressed high levels of Bt toxin. Transgenic plants were morphologically indistinguishable from untransformed plants and the introduced trait was inherited stably in the subsequent generations.

Efforts are now under way with the Kenya National Agricultural Institute and the Syngenta Foundation for Sustainable Agriculture to transfer these "clean events" to local varieties of maize in Kenya to provide resource-poor farmers with an additional option for insect control in the form they know best – the seed they plant. A similar approach is being used to enhance other important traits, such as abiotic stress tolerance and micronutrient content. Improved tolerance to stresses such as drought would directly benefit farmers, and biofortified plants could have a significant impact on children's health in developing countries.

[1] *The authors are, respectively, Cell Biologist and Director of the Applied Biotechnology Center of CIMMYT in Mexico.*

to 7 July 2003, landmark agreements were adopted on principles for the evaluation of food derived from modern biotechnology (FAO/WHO, 2003a), and on guidelines for the conduct of food safety assessment of foods derived from recombinant-DNA plants (FAO/WHO, 2003b) and from foods produced using recombinant-DNA micro-organisms (FAO/WHO, 2003c). A fourth document on labelling remains under discussion.

These Codex guidelines indicate that the safety assessment process for a transgenic food should be conducted through comparing it with its traditional counterpart, which is generally considered as safe because of a long history of use, focusing on the determination of similarities and differences. If any safety concern is identified, the risk associated with it should be characterized to determine its relevance to human health. This begins with the description of the host and donor organisms and the characterization of the genetic modification. The subsequent safety assessment should consider factors such as toxicity, tendencies to provoke allergic reaction (allergenicity), effects of changed composition of key nutrients (antinutrients) and metabolites, the stability of the inserted gene and nutritional modification associated with genetic modification. If the entire assessment of these factors concludes that the GM food in question is as safe as its conventional counterpart, the food is then considered safe to eat.

Critics of this comparative approach argue that non-targeted methods that analyse the content of whole foods are needed to assess both intended and unintended effects (ICSU). Scientists generally agree that transgenic foods should be assessed on a case-by-case basis, focusing on the particular product rather than on the process by which it was created. They also agree that the safety of GM foods should be assessed before they are put on the market, because postmarket monitoring is likely to be difficult, expensive and may not yield useful data because of the complex composition of diets and genetic variability in populations (ICSU).

Principles for the risk analysis of foods derived from modern biotechnology

The *Principles* define modern biotechnology as in the Cartagena Biosafety Protocol, and include principles on risk assessment, risk management and risk communication. The *Principles* acknowledge that the risk analysis approaches used to assess chemical hazards for substances such as pesticide residues, contaminants, food additives and processing aids are difficult to apply to whole foods. The risk assessment principles clarify that risk assessment includes a safety assessment designed to identify whether a hazard, nutritional or other safety concern is present and, if so, to gather information on its nature and severity. They reflect the concept of substantial equivalence whereby the safety assessment should include, but should not be substituted for, a comparison between the food derived from modern biotechnology and its conventional counterpart. The comparison should determine similarities and differences between the two. A safety assessment should (a) account for intended and unintended effects, (b) identify new or altered hazards and (c) identify changes relevant to human health in key nutrients. Safety assessment should take place on a case-by-case basis.

Risk management measures are to be proportional to the risk. These should take into account, where relevant, "other legitimate measures" according to general decisions of the Codex Commission and the *Codex working principles on risk analysis* (FAO/WHO, 2003d). Different risk management measures can meet the same objective. Risk managers are to account for the uncertainties identified in the risk assessment and manage the uncertainties. Risk management measures could include food labelling, conditions on marketing approvals, postmarketing monitoring and development of methods to detect or identify foods derived from modern biotechnology. The tracing of the product may also be useful for the smooth operation of the risk management measure.

The risk communication principles are premised on the ideal that effective communication is essential in all phases of risk assessment and management. It is to be an interactive process stimulating advice and stakeholder participation. Processes should be transparent, fully documented and open to public scrutiny while respecting legitimate concerns for confidential commercial information. Safety assessment reports and other aspects of the decision-making process should be available to the public. Responsive consultation processes should be created.

Guideline for the conduct of food safety assessment of foods derived from recombinant-DNA plants

The *Guideline for the conduct of food safety assessment of foods derived from recombinant-DNA plants* was also adopted by the 26th session (July 2003). The *Guideline* is designed to support the

BOX 21
Genetically modified crops as animal feed

Genetically modified crops, products derived from them and enzymes derived from genetically modified micro-organisms are widely used in animal feeds. The global animal feed market is estimated at some 600 million tonnes. Compound feeds are principally used for poultry, pigs and dairy cows and are formulated from a range of raw materials, including maize and other cereals and oilseeds such as soybeans and canola. It is currently estimated that 51 percent of the global area of soybeans, as well as 12 percent of canola and 9 percent of maize (used as whole maize and by-products such as maize gluten feed) is genetically modified (James, 2002a).

Safety assessments of novel livestock feeds in Canada, the United States and elsewhere look at the molecular, compositional, toxicological and nutritional characteristics of the novel feed compared with its conventional counterpart. Considerations include the effects on the animal eating the feed and on consumers eating the resulting animal product, worker safety and other environmental aspects of using the feed. In addition, comparisons of nutritional composition and wholesomeness between animal feeds containing transgenic versus conventional components have been the subject of many studies.

The major concerns associated with the use of GM products in animal feeds are whether modified DNA from the plant may be transferred into the food chain with harmful consequences and whether antibiotic-resistance marker genes used in the transformation process may be transferred to bacteria in the animal and hence potentially into human pathogenic bacteria. As the production process for the enzymes used in animal feeds takes place under controlled conditions in closed fermentation tank installations and eliminates the modified DNA from the final products, these products do not pose any risk to the animal or the environment. The enzyme phytase has particular benefits in feeding pigs and poultry, including a significant reduction in the amount of phosphorus released to the environment.

Researchers have examined the effects of feed processing on DNA to ascertain whether modified DNA remains intact and moves into the food chain. It has been found that DNA is not fragmented to any great extent in raw plant material and silage, but remains partially or fully intact. This means that, if GM crops are fed to animals, animals would be likely to be eating modified DNA. In order to consider whether modified DNA or derived proteins

Principles for the risk analysis of foods derived from modern biotechnology. It describes the recommended approach for making a safety assessment of foods derived from recombinant-DNA plants where a conventional counterpart exists. A conventional counterpart is defined as "a related plant variety, its components and/or products for which there is experience of establishing safety based on a common use as food". The techniques described in the *Guideline* may be applied to foods derived from plants that have been altered by techniques other than modern biotechnology.

The *Guideline* provides an introduction and rationale for food safety assessment of recombinant-DNA plants, drawing distinctions between it and conventional toxicological risk assessment for individual compounds that rely on animal studies. The "goal of the assessment is a conclusion as to whether the new food is as safe as and no less nutritious than the conventional counterpart against which it is compared". The *Guideline* indicates that substantial equivalence is not a safety assessment *per se*. Rather, it represents a starting point to structure food safety assessments relative to a conventional counterpart. Substantial equivalence is used to identify similarities and differences between the new food and the conventional counterpart. The safety assessment then consumed by animals have the potential to affect animal health or to enter the food chain, it is necessary to consider the fate of these molecules within the animal. Digestion of nucleic acids (DNA and ribonucleic acid, RNA) occurs through the action of nucleases present in the mouth, the pancreas and intestinal secretions. In ruminants, additional microbial and physical degradation of feed occurs. Evidence suggests that more than 95 percent of DNA and RNA is completely broken down within the digestive system. In addition, research carried out on the digestion of transgenic proteins in *in vitro* culture has shown nearly complete digestion occurring within five minutes in the presence of the enzyme pepsin.

Of further concern is whether there can be transfer of antibiotic resistance from the marker genes used in the production of GM plants to micro-organisms in animals and thence to bacteria pathogenic to humans. A review commissioned by FAO has concluded that this is extremely unlikely to happen (Chambers and Heritage, 2004). Nevertheless, this paper concluded that markers which code for resistance to clinically significant antibiotics, critical for treating human infectious diseases, should not be used in the production of transgenic plants.

MacKenzie and McLean (2002) reviewed 15 feeding studies of dairy cattle, beef cattle, swine and chickens published between 1995 and 2001. The feeds studied were insect- and/or herbicide-resistant maize and soybeans. The animals were fed a transgenic or conventional product for time periods ranging from 35 days for poultry to two years for beef cattle. None of these studies found any adverse effects in the animals fed the transgenic products for any of the measured parameters, which included nutrient composition, body weight, feed intake, feed conversion, milk production, milk composition, rumen fermentation, growth performance or carcass characteristics. Two of the studies found slight improvements in feed conversion rates for the animals fed insect-resistant maize, possibly because of lower concentrations of aflatoxins, antinutrients that result from insect damage.

In summary, it may be concluded that the risks to human and animal health from the use of GM crops and enzymes derived from genetically modified micro-organisms as animal feed are negligible. Nevertheless, some countries do require labelling to indicate the presence of GM material in imports and products derived thereof.

assesses the safety of identified differences, taking into consideration unintended effects resulting from genetic modification. Risk managers subsequently judge this and design risk management measures as appropriate.

Guideline for the conduct of food safety assessment of foods produced using recombinant-DNA micro-organisms

This *Guideline* is also intended to provide guidance on the safety assessment procedure of foods that are produced by using recombinant-DNA micro-organisms, based on the risk assessment framework of the above-mentioned *Principles*. The interesting point in the case of recombinant-DNA micro-organisms is that the comparison is recommended not only between the recombinant-DNA micro-organisms and their conventional counterparts (micro-organisms) but also between the foods produced by using them and the original foods.

Codex text under discussion on the labelling of genetically modified foods

In addition to the principles and guidelines above, the *Draft guidelines for the labelling of foods obtained through certain techniques of genetic modification/genetic engineering* (FAO/WHO, 2003e) are still in an early stage of discussion and many sections are bracketed, meaning the language has not yet been agreed. The guideline is proposed to apply to labelling of foods and food ingredients in three situations, when they are: (1) significantly different from conventional counterparts; (2) composed of or contain GM/GE organisms or contain protein or DNA resulting from gene technology; and (3) when they are produced from but do not contain GM/GE organisms, protein or DNA from gene technology.

According to the ICSU, scientists do not fully agree about the appropriate role of labelling. Although mandatory labelling is traditionally used to help consumers identify foods that may contain allergens or other potentially harmful substances, labels are also used to help consumers who wish to select certain foods on the basis of their mode of production, on environmental (e.g. organic), ethical (e.g. fair trade) or religious (e.g. kosher) grounds. Countries differ in the types of labelling information that are mandatory or permitted. According to the ICSU, "labelling of foods as GM or non-GM may enable consumer choice as to the process by which the food is produced [but] it conveys no information as to the content of the foods, and whether there are any risks and/or benefits associated with particular foods." The ICSU suggests that more informative food labelling that explained the type of transformation and any resulting compositional changes could enable consumers to assess the risks and benefits of particular foods. (Chapter 6 contains a more complete discussion of labelling.)

Environmental implications

Agriculture of any type – subsistence, organic or intensive – affects the environment, so it is natural to expect that the use of new genetic techniques in agriculture will also affect the environment. The ICSU, the GM Science Review Panel and the Nuffield Council on Bioethics, among others, agree that the environmental impact of genetically transformed crops may be either positive or negative depending on how and where they are used. Genetic engineering may accelerate the damaging effects of agriculture or contribute to more sustainable agricultural practices and the conservation of natural resources, including biodiversity. The environmental concerns associated with transgenic crops are summarized below along with the current state of scientific knowledge regarding them.

Releasing transgenic crops into the environment may have direct effects including: gene transfer to wild relatives or conventional crops, weediness, trait effects on non-target species and other unintended effects. These risks are similar for transgenic and conventionally bred crops (ICSU). Although scientists differ in their views on these risks, they agree that environmental impacts need to be assessed on a case-by-case basis and recommend post-release ecological monitoring to detect any unexpected events (ICSU, Nuffield Council, GM Science Review Panel). Transgenic crops may also entail positive or negative indirect environmental effects through changes in agricultural practices such as pesticide and herbicide use and cropping patterns.

Transgenic trees involve similar environmental concerns, although there are additional concerns because of their long life cycle. Transgenic micro-organisms used in food processing are normally used under confined conditions and are generally not considered to pose environmental risks. Some micro-organisms can be used in the environment as biological control agents or for bioremediation of environmental damage (e.g. oil spills), and their environmental effects should be assessed prior to release. Environmental concerns related to transgenic fish primarily focus on their potential to breed with and outcompete wild relatives (ICSU). Transgenic farm animals would probably be used in highly confined conditions, so they would pose little risk of environmental damage (NRC, 2002) (Box 22 on pages 68–9).

Gene flow

Scientists agree that gene flow from GM crops is possible through pollen from open-pollinated varieties crossing with local crops or wild relatives. Because gene flow has happened for millennia between land races and conventionally bred crops, it is reasonable to expect that it could also happen with transgenic crops. Crops vary in their tendency to outcross, and the ability of a crop to outcross depends on the presence of sexually compatible wild relatives or crops, which varies according to location (Box 23 on page 70) (ICSU, GM Science Review Panel).

Scientists do not fully agree whether or not gene flow between transgenic crops and wild relatives matters, in and of itself (ICSU, GM Science Review Panel). If a resulting transgenic/wild hybrid had some competitive advantage over the wild population it could persist in the environment and potentially disrupt the ecosystem. According to the GM Science Review Panel, hybridization between transgenic crops and wild relatives seems "overwhelmingly likely to transfer genes that are advantageous in agricultural environments, but will not prosper in the wild … Furthermore, no hybrid between any crop and any wild relative has ever become invasive in the wild in the UK" (GM Science Review Panel, 2003: 19).

Whether the otherwise benign flow of transgenes into land races or other conventional varieties would itself constitute an environmental problem is a matter of debate, because conventional crops have long interacted with land races in this way (ICSU). Research is needed to improve the assessment of the environmental consequences of gene flow, particularly in the long run, and to understand better the gene flow between the major food crops and land races in centres of diversity (ICSU, GM Science Review Panel).

Weediness refers to the situation in which a cultivated plant or its hybrid becomes established as a weed in other fields or as an invasive species in other habitats. Scientists agree that there is only a very low risk of domesticated crops becoming weeds themselves because the traits that make them desirable as crops often make them less fit to survive and reproduce in the wild (ICSU, GM Science Review Panel). Weeds that hybridize with herbicide-resistant crops have the potential to acquire the herbicide-tolerant trait, although this would only provide an advantage in the presence of the herbicide (ICSU, GM Science Review Panel). According to the GM Science Review Panel, "Detailed field experiments on several GM crops in a range of environments have demonstrated that the transgenic traits investigated – herbicide tolerance and insect resistance – do not significantly increase the fitness of the plants in semi-natural habitats" (GM Science Review Panel, 2003:19). Some transgenic traits, such as pest or disease resistance, could provide a fitness advantage but there is little evidence so far that this happens or has any negative environmental consequences (ICSU, GM Science Review Panel). More evidence is required regarding the effect of fitness-enhancing traits on invasiveness (GM Science Review Panel).

Management and genetic methods are being developed to minimize the possibility of gene flow. The complete isolation of crops grown on a commercial scale, either GM or non-GM, is not currently practical although gene flow can be minimized, as it currently is between oilseed rape varieties grown for food, feed or industrial oils (GM Science Review Panel). Management strategies include avoiding the planting of transgenic crops in their centres of biodiversity or where wild relatives are present, or using buffer zones to isolate transgenic varieties from conventional or organic varieties. Genetic engineering can be used to alter flowering periods to prevent cross-pollination or to ensure that the transgenes are not incorporated in pollen and developing sterile transgenic varieties (ICSU and Nuffield Council). The GM Science Review Panel and other expert bodies recommend that GM crops that produce medical or industrial substances should be designed and grown in ways that would avoid gene flow to food and feed crops (GM Science Review Panel).

Trait effects on non-target species

Some transgenic traits – such as the pesticidal toxins expressed by Bt genes – may affect non-target species as well as the crop pests they are intended to control (ICSU). Scientists agree that this could happen but they disagree about how likely it is (ICSU, GM Science Review Panel). The monarch butterfly controversy (Box 24 on page 71) demonstrated that it is difficult to extrapolate from laboratory studies to field conditions. Field studies have shown some differences in soil microbial community structure between Bt and non-Bt crops, but these are within the normal range of variation found between cultivars of the same crop and do not provide convincing evidence that Bt crops could be damaging to soil health in the long term (GM Science Review Panel). Although no significant adverse effects on non-target wildlife or soil health have so far

BOX 22
Environmental concerns regarding genetically modified animals

No GM animals are currently being used in commercial agriculture anywhere in the world (Chapter 2), but several livestock and aquatic species are under research for a variety of transgenic traits. Studies of the potential environmental concerns associated with GM animals have been conducted recently by the United States National Research Council (NRC, 2002), the United Kingdom Agriculture and Environment Biotechnology Commission (AEBC, 2002) and the Pew Initiative on Food and Biotechnology (Pew Initiative, 2003). These studies conclude that GM animals may have either positive or negative effects on the environment depending on the particular animal, trait and production environment in which it is introduced. The main environmental concerns associated with animals involve: (a) the possibility that transgenic animals could escape with resultant negative effects on wild relatives or ecosystems, and (b) potential changes in production practices that may lead to varying degrees of environmental stress. These reports recommend that GM animals should be evaluated in relation to their conventional counterparts.

The three studies agree that transgenic animals should be evaluated for their ability to escape and become established in different environments. The NRC and AEBC agree that adverse environmental impacts are less likely for livestock breeds than for fish, because most farm animal species have no wild relatives remaining and farm animal reproduction is confined to managed herds and flocks. The danger of becoming feral is low in cattle, sheep and domestic chickens, which are less mobile and highly domesticated, but higher in horses, camels, rabbits, dogs and laboratory animals (rats and mice). Non-transgenic domestic goats, pigs and cats have been known to become feral, causing extensive damage to ecological communities (NRC, 2002). Transgenic farm animals would be particularly valuable and therefore would be kept in carefully controlled environments. Aquacultured fish, by contrast, are naturally mobile and breed easily with wild species. The AEBC report recommends that transgenic fish should not be raised in offshore pens owing to the high probability of escape. The Pew Initiative study points out that the impact of escaped aquaculture fish,

been observed in the field, scientists disagree regarding how much evidence is needed to demonstrate that growing Bt crops is sustainable in the long term (GM Science Review Panel). Scientists agree that the possible impacts on non-target species should be monitored and compared with the effects of other current agricultural practices such as chemical pesticide use (GM Science Review Panel). They acknowledge that they need to develop better methods for field ecological studies, including better baseline data with which to compare new crops (ICSU).

Indirect environmental effects

Transgenic crops may have indirect environmental effects as a result of changing agricultural or environmental practices associated with the new varieties. These indirect effects may be beneficial or harmful depending on the nature of the changes involved (ICSU, GM Science Review Panel). Scientists agree that the use of conventional agricultural pesticides and herbicides has damaged habitats for farmland birds, wild plants and insects and has seriously reduced their numbers (ICSU, GM Science Review Panel, Royal Society). Transgenic crops are changing chemical and land-use patterns and farming practices, but scientists do not fully agree whether the net effect of these changes will be positive or negative for the environment (ICSU). Scientists acknowledge that more comparative analysis of new technologies and current farming practices is needed.

Pesticide use

The scientific consensus is that the use of transgenic insect-resistant Bt crops whether transgenic or conventionally bred, depends on their "net fitness" compared with wild species. It argues that transgenic traits could increase or decrease the net fitness of farmed species, and recommends that transgenic fish be carefully evaluated and regulated in an integrated and transparent way.

Transgenic animals could also lead to environmental impacts through changes in the animals themselves or in the management practices associated with them. Transgenic modifications could reduce the amount of manure and methane emissions produced by livestock and aquaculture species (AEBC, 2002; Pew Initiative, 2003) or increase their resistance to diseases (promoting lower antibiotic usage). On the other hand, some genetic modifications could lead to more intensive livestock production with associated increases in environmental pollutants. The question of environmental harm is therefore less a question of the technology itself than of the capacity to manage it.

An additional factor to consider with livestock biotechnology is the possible effects on the welfare of animals. These welfare effects may be positive or negative and should be evaluated against conventional livestock management practices (AEBC, 2002). At present, the production of transgenic and cloned animals is extremely inefficient, with high mortality during early embryonic development and success rates of only 1–3 percent. Of the transgenic animals born, the inserted genes may not function as expected, often resulting in anatomical, physiological and behavioural abnormalities (NRC, 2002). Cattle produced by cloning methods tend to have longer gestation periods and higher birth weights, resulting in a higher rate of Caesarean births (NRC, 2002; AEBC, 2002). Such problems can also occur with animals produced using AI/MOET, and should be evaluated in the context of the other reproductive technologies used in livestock production (AEBC, 2002). The AEBC report further recommends that the potential welfare effects of all technologies used in animal agriculture should be weighed against economic and environmental considerations.

is reducing the volume and frequency of insecticide use on maize, cotton and soybean (ICSU). These results have been especially significant for cotton in Australia, China, Mexico, South Africa and the United States (Chapter 4). The environmental benefits include less contamination of water supplies and less damage to non-target insects (ICSU). Reduced pesticide use suggests that Bt crops would be generally beneficial to in-crop biodiversity in comparison with conventional crops that receive regular, broad-spectrum pesticide applications, although these benefits would be reduced if supplemental insecticide applications were required (GM Science Review Panel). As a result of less chemical pesticide spraying on cotton, demonstrable health benefits for farm workers have been documented in China (Pray *et al.*, 2002) and South Africa (Bennett, Morse and Ismael, 2003).

Herbicide use

Herbicide use is changing as a result of the rapid adoption of HT crops (ICSU). There has been a marked shift away from more toxic herbicides to less toxic forms, but total herbicide use has increased (Traxler, 2004). Scientists agree that HT crops are encouraging the adoption of low-till crops with resulting benefits for soil conservation (ICSU). There may be potential benefits for biodiversity if changes in herbicide use allow weeds to emerge and remain longer in farmers' fields, thereby providing habitats for farmland birds and other species, although these benefits are speculative and have not been strongly supported by field trials to date (GM Science Review

BOX 23

An ecologist's view of gene flow from transgenic crops

Allison A. Snow[1]

Most ecological scientists agree that gene flow is not an environmental problem unless it leads to undesirable consequences. In the short term, the spread of transgenic herbicide resistance via gene flow may create logistical and/or economic problems for growers. Over the long term, transgenes that confer resistance to pests and environmental stress and/or lead to greater seed production have the greatest likelihood of aiding weeds or harming non-target species. However, these outcomes seem unlikely for most currently grown transgenic crops. Many transgenic traits are likely to be innocuous from an environmental standpoint, and some could lead to more sustainable agricultural practices. To document various risks and benefits, there is a great need for academic researchers and others to become more involved in studying transgenic crops. Similarly, it is crucial that molecular biologists, crop breeders and industry improve their understanding of ecological and evolutionary questions about the safety of new generations of transgenic crops.

The presence of wild and weedy relatives varies among countries and regions. The chart shows examples of major crops grouped by their ability to disperse pollen and the occurrence of weedy relatives in the continental United States. This simple 2 x 2 matrix can be useful in identifying cases where gene flow from a transgenic crop to a wild relative is likely. For crops where no wild or weedy relatives are grown nearby – as with soybean, cotton and maize shown here in green – gene flow to the wild would not occur. Rice, sorghum and wheat have wild relatives in the United States and a relatively low tendency to outcross, which could allow transgenes to disperse into wild populations. The crops that have a high tendency to outcross and have wild relatives in the United States are shown in red. There is a high potential for gene flow between these crops and their wild relatives, so care should be taken in growing transgenic varieties that might confer a competitive advantage on their hybrids.

[1] *Dr Snow is a Professor in the Department of Evolution, Ecology, and Organismal Biology at The Ohio State University, United States.*

POTENTIAL FOR OUTCROSSING	COMPATIBLE WEEDY RELATIVES NEARBY: NO	COMPATIBLE WEEDY RELATIVES NEARBY: YES
LOW	SOYBEAN	RICE SORGHUM WHEAT
HIGH	COTTON MAIZE	SUNFLOWER BRASSICAS CARROT SQUASH RADISH POPLAR

BOX 24
Does Bt maize kill monarch butterflies?

John Losey, an entomologist at Cornell University, published a research paper in the scientific journal *Nature* that seemed to prove that pollen from Bt maize killed monarch butterflies (Losey, Rayor and Carter, 1999). Losey and his colleagues found that when they spread the pollen from a commercial variety of Bt maize on milkweed leaves in the laboratory and fed them to monarch butterfly caterpillars, the caterpillars died.

Six independent teams of researchers conducted follow-up studies on the effects of Bt maize pollen on monarch butterfly caterpillars, published in 2001 in the *Proceedings of the National Academy of Sciences of the United States of America*. Although these studies agreed that the pollen used in the original study was toxic at high doses, they found that Bt maize pollen posed negligible risk to monarch larvae under field conditions. They based their conclusion on four facts: (a) the Bt toxin is expressed at fairly low levels in the pollen of most commercial Bt maize varieties, (b) maize and milkweed (the normal food of monarch butterfly caterpillars) are generally not found together in the field, (c) there is limited overlap in the time periods when maize pollen sheds in the field and monarch larvae are active and (d) the amount of pollen likely to be consumed under field conditions was not toxic. These studies concluded that the risk of harm to monarch butterfly caterpillars from Bt maize pollen is very small, particularly in comparison with other threats such as conventional pesticides and drought (Conner, Glare and Nap, 2003).

Many scientists are frustrated by the way the monarch butterfly controversy and other issues related to biotechnology were handled in the press. Although the original monarch butterfly study received worldwide media attention, the follow-up studies that refuted it did not receive the same amount of coverage. As a result, many people are not aware that Bt maize poses very little risk to monarch butterflies (Pew Initiative, 2002a).

Panel). There is concern, however, that greater use of herbicides – even less toxic herbicides – will further erode habitats for farmland birds and other species (ICSU). The Royal Society has published the results of extensive farm-scale evaluations of the impacts of transgenic HT maize, spring oilseed rape (canola) and sugar beet on biodiversity in the United Kingdom. These studies found that the main effect of these crops compared with conventional cropping practices was on weed vegetation, with consequent effects on the herbivores, pollinators and other populations that feed on it. These groups were negatively affected in the case of transgenic HT sugar beet, positively affected in the case of maize and showed no effect in spring oilseed rape. They conclude that commercialization of these crops would have a range of impacts on farmland biodiversity, depending on the relative efficacy of transgenic and conventional herbicide regimes and the degree of buffering provided by surrounding fields (Royal Society, 2003: 1912). Scientists acknowledge that there is insufficient evidence to predict what the long-term impacts of transgenic HT crops will be on weed populations and associated in-crop biodiversity (GM Science Review Panel).

Pest and weed resistance

Scientists agree that extensive long-term use of Bt crops and glyphosate and gluphosinate, the herbicides associated with HT crops, can promote the development of resistant insect pests and weeds (ICSU, GM Science Review Panel). Similar breakdowns have routinely occurred with conventional crops and pesticides and, although the protection conferred by Bt genes appears to be particularly robust, there is no reason to assume that resistant pests will not develop (GM Science Review Panel). Worldwide, over 120 species of weeds have developed resistance to the dominant herbicides used with HT crops, although the resistance is not necessarily associated with transgenic varieties (ICSU, GM Science Review Panel). Because the development of resistant pests and weeds can be expected if Bt and glyphosate and gluphosinate are overused, scientists advise that a resistance management strategy be used when transgenic crops are planted (ICSU). Scientists disagree about how effectively resistance management strategies can be employed, particularly in developing countries (ICSU). The extent and possible severity of impacts of resistant pests or weeds on the environment are subject to debate (GM Science Review Panel).

Abiotic stress tolerance

As we saw in Chapter 2, new transgenic crops with tolerance to various abiotic stresses (e.g. salt, drought, aluminium) are being developed that may allow farmers to cultivate soils that were previously not arable. Scientists agree that these crops may be environmentally beneficial or harmful depending on the particular crop, trait and environment (ICSU).

Environmental impact assessment

There is broad consensus that the environmental impacts of transgenic crops and other living modified organisms (e.g. transgenic seeds) should be evaluated using science-based risk assessment procedures on a case-by-case basis depending on the particular species, trait and agro-ecosystem. Scientists also agree that the environmental release of transgenic organisms should be compared with other agricultural practices and technology options (ICSU and Nuffield Council).

As we saw above, food safety assessment procedures are well developed and the FAO/WHO Codex Alimentarius Commission provides an international forum for developing food safety guidelines for transgenic foods. By contrast, there are no internationally agreed guidelines and standards for assessing the environmental impacts of transgenic organisms (ICSU). Scientists agree that there is a need for internationally and regionally harmonized methodologies and standards for assessing environmental impacts in different ecosystems (ICSU; FAO, 2004). The role of international standard-setting bodies in providing guidance for risk analysis is described below.

According to the ICSU, regulators in different countries typically require similar types of data for environmental impact assessments, but they differ in their interpretation of these data and of what constitutes an environmental risk or harm. Scientists also differ on what the appropriate basis for comparison should be: with current agricultural systems and/or baseline ecological data (ICSU). An FAO expert consultation (2004) agreed that the impacts of agriculture on the environment were much greater than the measurable impacts of a shift from conventional to transgenic crops, so the basis of comparison is important.

Scientists also disagree about the value of small-scale laboratory and field trials and their extrapolation to large-scale effects, and it is unclear whether modelling approaches that incorporate data from geographical information systems would be useful in predicting the effects of living modified organisms (LMOs) in different ecosystems (ICSU). The scientific community recommends that more research is needed on the post-release effects of transgenic crops. There is also a need for more targeted post-release monitoring and better methodologies for monitoring (ICSU; FAO, 2004).

International environmental agreements and institutions

Several international agreements and institutions are relevant to the environmental aspects of certain transgenic products, among them the Convention on Biological Diversity, the Cartagena Protocol on Biosafety and the International Plant Protection Convention. The roles and provisions of these bodies are described below.

The Convention on Biological Diversity and the Cartagena Protocol on Biosafety

Most of the measures of the Convention on Biological Diversity (CBD) (Secretariat of the Convention on Biological Diversity, 1992) focus on the conservation of ecosystems; however, two aspects concerning the conservation of biological diversity are relevant for biosafety – the management of risks associated with LMOs resulting from biotechnology and the management of risks associated with alien species.

In the context of *in-situ* conservation measures, the Convention requires contracting parties "… to regulate, manage or control the risks associated with the use and release of living modified organisms resulting from biotechnology which are likely to have adverse environmental impacts that could affect the conservation and sustainable use of biological diversity …". This provision goes beyond the general scope of the Convention in that it requires also that risks to human health are taken into account.

The Convention establishes that contracting parties have the obligation to prevent the introduction of alien species and to control or to eradicate those alien species that threaten ecosystems, habitats or species. Invasive alien species are considered as species introduced deliberately or unintentionally outside their natural habitats where they have the ability to establish themselves, invade, replace natives and take over the new environment.

The Cartagena Protocol on Biosafety (Secretariat of the Convention on Biological Diversity, 2000) was adopted by the CBD in September 2000 and came into force in September 2003. The objective of the Protocol is to protect biological diversity from the potential risks posed by safe transfer, handling and use of LMOs resulting from modern biotechnology. Risks to human health are also considered. The Protocol is applicable to all LMOs, except pharmaceuticals for humans that are addressed by other international agreements or organizations.

The Protocol sets out an Advance Informed Agreement (AIA) procedure for LMOs intended for intentional introduction into the environment that may have adverse effects on the conservation and sustainable use of biodiversity. The procedure requires, prior to the first intentional introduction into the environment of an importing party:

- notification of the party of export containing certain information;
- acknowledgement of its receipt; and
- the written consent of the party of import.

Four categories of LMO are exempted from the AIA: LMOs in transit, LMOs for contained use, LMOs identified in a decision of the Conference of Parties/Meeting of Parties as not likely to have adverse effects on biodiversity conservation and sustainable use, and LMOs intended for direct use as food, feed or for processing.

For LMOs that may be subject to transboundary movement for direct use as food or feed, or for processing, Article 11 provides that a party that makes a final decision for domestic use, including placing on the market, must notify the Biosafety Clearing-House established under the Protocol. The notification is to contain minimum information required under Annex II. A contracting party may take an import decision under its domestic regulatory framework, provided this is consistent with the Protocol. A developing country contracting party, or a party with a transition economy that lacks a domestic regulatory framework, can declare through the Biosafety Clearing-House that its decision on the first import of an LMO for direct use as food, feed or for processing will be pursuant to a risk assessment. In both cases lack of scientific certainty because of insufficient relevant scientific information and knowledge regarding the extent of potential adverse effects shall not prevent the contracting party of import from taking a decision, as appropriate, in order to avoid or minimize potential adverse effects.

Risk assessment and risk management are requirements for both AIA and Article 11 cases. The risk assessment must be consistent with criteria enumerated in an annex. In principle, risk assessment is to be carried out by competent national decision-making authorities. The exporter may be required to undertake the assessment. The importing party may require the notifier to pay for the risk assessment.

The Protocol specifies general risk management measures and criteria. Any measures based on risk assessment should be proportionate to the risks identified. Measures to minimize the likelihood of unintentional transboundary movement of LMOs are to be taken. Affected or potentially affected states are to be notified when an occurrence may lead to an unintentional transboundary movement.

The Protocol also contains provisions on LMO handling, packaging and transportation (Article 18). In particular, each contracting party is to take measures to require documentation that:

(a) for LMOs intended for direct use as food or feed, or for processing, clearly identifies that they "may contain" LMOs and are "not intended for intentional introduction into the environment", and a contact point for further information;
(b) for LMOs destined for contained use, clearly identifies them as LMOs and specifies any requirements for safe handling, storage, transport and use, and a contact point and consignee;
(c) for LMOs intended for intentional introduction into the environment of the party of import, clearly identifies them as LMOs and specifies the identity and traits/characteristics, any requirements for safe handling, storage, transport and use, and a contact point, the name/address of the importer/exporter and a declaration that the movement conforms to the Protocol's requirements applicable to the exporter.

Information exchange is envisaged in the Protocol through the establishment of the Biosafety Clearing-House. The Biosafety Clearing-House is intended to facilitate the exchange of information on, and experience with, LMOs and to assist parties in implementation of the Protocol. Pursuant to Article 20, paragraph 2, it shall also provide access to other international biosafety information exchange systems. Information that parties are required to provide to the Clearing-House includes existing laws, regulations and guidelines for implementation of the Protocol; information required for the AIA; any bilateral, regional and multilateral agreements within the context of the Protocol; summaries of risk assessment and final decisions.

Public participation is specifically addressed in Article 23. Contracting parties shall:

(a) promote and facilitate public awareness, education and participation concerning safe transfer, handling and use of LMOs;
(b) endeavour to ensure public awareness and education encompasses access to information on LMOs identified by the Protocol that may be imported;
(c) consult the public in the decision-making process regarding LMOs and shall make decisions available to the public in accordance with national laws and regulations. Confidential information is to be respected in those activities.

Socio-economic considerations are allowed in decision-making. Contracting parties may account for socio-economic considerations arising from the impact of LMOs on biodiversity conservation and sustainable use, especially with regard to the value of biodiversity to indigenous and local communities. The parties are encouraged to cooperate on research and information exchange on any socio-economic impacts of LMOs. A process to address liability and redress for damage resulting from LMO transboundary movements is to be set up by the first meeting of parties to the Protocol.

The IPPC and living modified organisms

The purpose of the International Plant Protection Convention (IPPC) is to secure common and effective action to prevent the spread and introduction of pests of plants and plant products, and to promote measures for their control. Although the IPPC makes provision for trade in plants and plant products, it is not limited in this respect. Specifically, the scope of the IPPC extends to the protection of wild flora in addition to cultivated flora, and covers both direct and indirect damage from pests, including weeds. The IPPC plays an important role in the conservation of plant biodiversity and in the protection of natural resources. Hence, standards developed under the IPPC are also applicable to key elements of the CBD, including the prevention and mitigation of impacts of alien invasive species, and the Cartagena Protocol on Biosafety. As a consequence, the CBD, FAO and IPPC have established a close collaborative relationship. This has in particular extended to the inclusion of CBD concerns in the development of new international standards for phytosanitary measures (ISPMs).

ISPMs developed under the auspices of the IPPC provide internationally agreed guidance to countries on measures to protect plant life or health from the introduction and spread of pests or diseases. One of the most important concept standards developed under the IPPC is ISPM No. 11, *Pest risk analysis for quarantine pests* (FAO, 2001b), adopted by the Interim Commission on Phytosanitary Measures (ICPM) at its 3rd Session in 2001. In addition, the ICPM, at its 5th Session in 2003, adopted a supplement to ISPM No. 11 to address risks to the environment in order to take into account CBD concerns, especially with regard to invasive alien species. More recently, the IPPC has drafted another supplement to ISPM No. 11 to address pest risk analysis for LMOs.[8]

This draft standard has undergone extensive technical discussion and consultation throughout its development. At the request of the ICPM, an open-ended expert working group was convened in September 2001 and included government-nominated experts from developed and developing countries and experts representing both plant protection and environmental concerns. The purpose of the meeting was to discuss the development of this standard and the need to provide detailed guidance on conducting risk analyses to address the potential plant health effects of LMOs with particular attention to the needs of developing countries.

The working group considered that potential phytosanitary risks of LMOs that may need to be considered in a pest risk analysis include (FAO, 2002b):

- Changes in adaptive characteristics that may increase the potential invasiveness including, for example: drought tolerance of plants; herbicide tolerance of plants; alterations in reproductive biology; dispersal ability of pests; pest resistance; and pesticide resistance.
- Gene flow including, for example: transfer of herbicide resistance genes to compatible species; and the potential to overcome existing reproductive and recombination barriers.
- Potential to affect non-target organisms adversely including, for example: changes in host range of biological control agents or organisms claimed to be beneficial; and effects on other organisms such as biological control agents, beneficial organisms and soil microflora that result in a phytosanitary impact (indirect effects).
- Possibility of phytopathogenic properties including, for example: phytosanitary risks presented by novel traits in organisms not normally considered a phytosanitary risk; enhanced virus recombination, trans-encapsidation and synergy events related to the presence of virus sequences; and phytosanitary risks associated with nucleic acid sequences (markers, promoters, terminators, etc.) present in the insert.

Subsequently, a small working group, including CBD/Cartagena Protocol and plant protection experts, met to prepare a draft standard that would provide general guidelines on the conduct of pest risk analysis with respect to the potential phytosanitary risks identified above. In the process of drafting the standard, the working group noted several important issues with regard to the scope of the IPPC and potential phytosanitary risks of LMOs. In particular, the working group noted that whereas some types of LMO would require pest risk analyses because they could present phytosanitary risks, many other categories of LMO, e.g. those with modified characteristics such as ripening time or storage/shelf life, do not present phytosanitary risks. Similarly, it was noted that pest risk analysis would only address the phytosanitary risks of LMOs, but that other potential risks may also need to be addressed (e.g. human health concerns for food products). It was also noted that the potential phytosanitary risks identified above could also be associated with non-LMOs, or conventionally bred crops. It was acknowledged that risk analysis procedures of the IPPC are generally concerned with phenotypic characteristics rather than genotypic characteristics and it was noted that the latter may need to be considered when assessing the phytosanitary risks of LMOs.

At the time of the publication of this document, the draft standard has been

[8] The Cartagena Protocol on Biosafety defines a living modified organism (LMO) as "any living organism that possesses a novel combination of genetic material obtained through the use of modern biotechnology" (Secretariat of the Convention on Biological Diversity, 2000: 4).

reviewed by the Standards Committee and been distributed to all members for review and comment. Comments on the draft standard received from countries were reviewed by the Standards Committee in November 2003. The draft standard will be modified taking into account received comments, and should be submitted to the ICPM at its 6th Session in April 2004 for its approval.

Conclusions

Thus far, in those countries where transgenic crops have been grown, there have been no verifiable reports of them causing any significant health or environmental harm. Monarch butterflies have not been exterminated. Pests have not developed resistance to Bt. Some evidence of HT weeds has emerged, but superweeds have not invaded agricultural or natural ecosystems. On the contrary, some important environmental and social benefits are emerging. Farmers are using less pesticide and are replacing toxic chemicals with less harmful ones. As a result, farm workers and water supplies are protected from poisons, and beneficial insects and birds are returning to farmers' fields.

Meanwhile, science is moving ahead rapidly. Some of the concerns associated with the first generation of transgenic crops have technical solutions. New techniques of genetic transformation are eliminating the antibiotic marker genes and promoter genes that are of concern to some. Varieties including two different Bt genes are reducing the likelihood that pest resistance will develop. Management strategies and genetic techniques are evolving to prevent gene flow.

However, the lack of observed negative effects so far does not mean they cannot occur, and scientists agree that our understanding of ecological and food safety processes is incomplete. Much remains unknown. Complete safety can never be assured, and regulatory systems and the people who manage them are not perfect. How should we proceed given the lack of scientific certainty? The GM Science Review Panel (p. 25) argues that:

> *There is a clear need for the science community to do more research in a number of areas, for companies to make good choices in terms of transgene design and plant hosts, and to develop products that meet wider societal wishes. Finally, the regulatory system … should continue to operate so that it is sensitive to the degree of risk and uncertainty, recognises the distinctive features of GM, divergent scientific perspectives and associated gaps in knowledge, as well as taking into account the conventional breeding context and baselines.*

The Nuffield Council (p. 44) recommends that "the same standards should be applied to the assessment of risks from GM and from non-GM plants and foods, and that the risks of inaction be given the same careful analysis as risks of action …" They further conclude (p. 45):

> *We do not take the view that there is enough evidence of actual or potential harm to justify a moratorium on either research, field trials, or the controlled release of GM crops into the environment at this stage. We therefore recommend that research into GM crops be sustained, governed by a reasonable application of the precautionary principle.*

FAO's *Statement on biotechnology* (FAO, 2000b) concurs:

> *FAO supports a science-based evaluation system that would objectively determine the benefits and risks of each individual GMO. This calls for a cautious case-by-case approach to address legitimate concerns for the biosafety of each product or process prior to its release. The possible effects on biodiversity, the environment and food safety need to be evaluated, and the extent to which the benefits of the product or process outweigh its risks assessed. The evaluation process should also take into consideration experience gained by national regulatory authorities in clearing such products. Careful monitoring of the post-release effects of these products and processes is also essential to ensure their continued safety to human beings, animals and the environment.*

Science cannot declare any technology completely risk free. Genetically engineered crops can reduce some environmental risks associated with conventional agriculture, but will also introduce new challenges that must be addressed. Society will have to decide when and where genetic engineering is safe enough.

6. Public attitudes to agricultural biotechnlogy

Public attitudes to biotechnology will play an important role in determining how widely genetic engineering techniques will be adopted in food and agriculture. Public opinion has been studied extensively in Europe and North America but less so in other countries, and internationally comparable data are very limited. This chapter reviews the largest internationally comparable public opinion studies that have been conducted so far on agricultural biotechnology (Hoban, 2004). It concludes with a discussion of the possible role of labelling to address the differences in public attitudes towards transgenic foods.

Not surprisingly, public attitudes to agricultural biotechnology differ widely across countries, with people from Europe generally expressing more negative views than those from the Americas, Asia and Oceania. Attitudes are generally related to income levels, with people from poorer countries having more positive attitudes than those from wealthier countries, though there are exceptions to this pattern. Although these surveys are not very precise (for example, they often use the terms "biotechnology" and "genetic engineering" interchangeably – see Box 25), they find that people have fairly nuanced views. Although some people consider all applications of genetic engineering objectionable, most people make subtle distinctions, considering the type of modification and the potential risks and benefits.

Benefits and risks of biotechnology

The most extensive international study of public perceptions of biotechnology is a survey of about 35 000 people in 34 countries in Africa, Asia, the Americas, Europe and Oceania (see list in Figure 10) and conducted by Environics International[9] (2000). About 1 000 people in each country were asked the extent to which they agreed or disagreed with the following statement:

> *The benefits of using biotechnology to create genetically modified food crops that do not require chemical pesticides and herbicides are greater than the risk.*

The responses to this statement reveal some important differences by region (Figure 10). People in the Americas, Asia and Oceania were far more likely than Africans or Europeans to agree that the benefits of this use of biotechnology outweigh the risks. Whereas almost three-fifths of the people surveyed in the Americas, Asia and Oceania responded positively, only slightly more than one-third of the Europeans and slightly less than half of the Africans agreed. People in Africa and Europe were also more ambivalent in their responses, with one-fifth and one-third, respectively, saying they were not sure compared with only one-eighth in the Americas, Asia and Oceania.

In general, people in higher-income countries tend to be more sceptical of the benefits of biotechnology and more concerned about the potential risks, although there are exceptions to this pattern. Within Asia, for example, higher-income countries such as Japan and the Republic of Korea are more sceptical of the benefits and more concerned about the potential risks associated with biotechnology than people from lower-income countries such as the Philippines and Indonesia. Similarly, in Latin America, people in higher-income countries such as Argentina and Chile are more sceptical than are people from lower-income countries such as the Dominican Republic and Cuba. There are exceptions to this observation, however. Within Europe, for example, people from the higher-income country of the Netherlands are more positive about biotechnology on average than those from the lower-income Greece. Clearly factors other than income levels are important in determining attitudes towards biotechnology.

[9] In November 2003, Environics International became known as GlobeScan Inc.

BOX 25
Asking the right questions

Responses to public opinion polls depend, among other things, on the precise phrasing of the questions. Research has shown that asking about "biotechnology" is more likely to elicit a positive response than asking about "genetic engineering". Although such subtleties can lead to a 10–20 percent shift in the balance of responses, many studies use these terms very loosely. Other factors can influence responses, such as the way in which respondents are selected and the type and amount of background material made available to them. For these reasons, comparisons of different studies across space and time should be made with caution.

Within Asia and Oceania, the range of opinion varied widely, from 81 percent agreement in Indonesia to only 33 percent in Japan. Higher-income countries in Asia and Oceania – Australia, Japan and the Republic of Korea – were generally less likely to agree that the benefits of using biotechnology to reduce chemical pesticide and herbicide use outweigh the risks than were other countries in the region. The range of opinion within the Americas was not as wide, ranging from 79 percent agreement in Cuba to 44 percent in Argentina. Within Latin America and the Caribbean, the higher-income countries of Argentina, Chile and Uruguay were somewhat more negative than the others. Within North America, agreement with this statement was consistently high. European opinion was generally less accepting than in other regions, ranging from 55 percent agreement in the Netherlands to 22 percent in France and Greece.

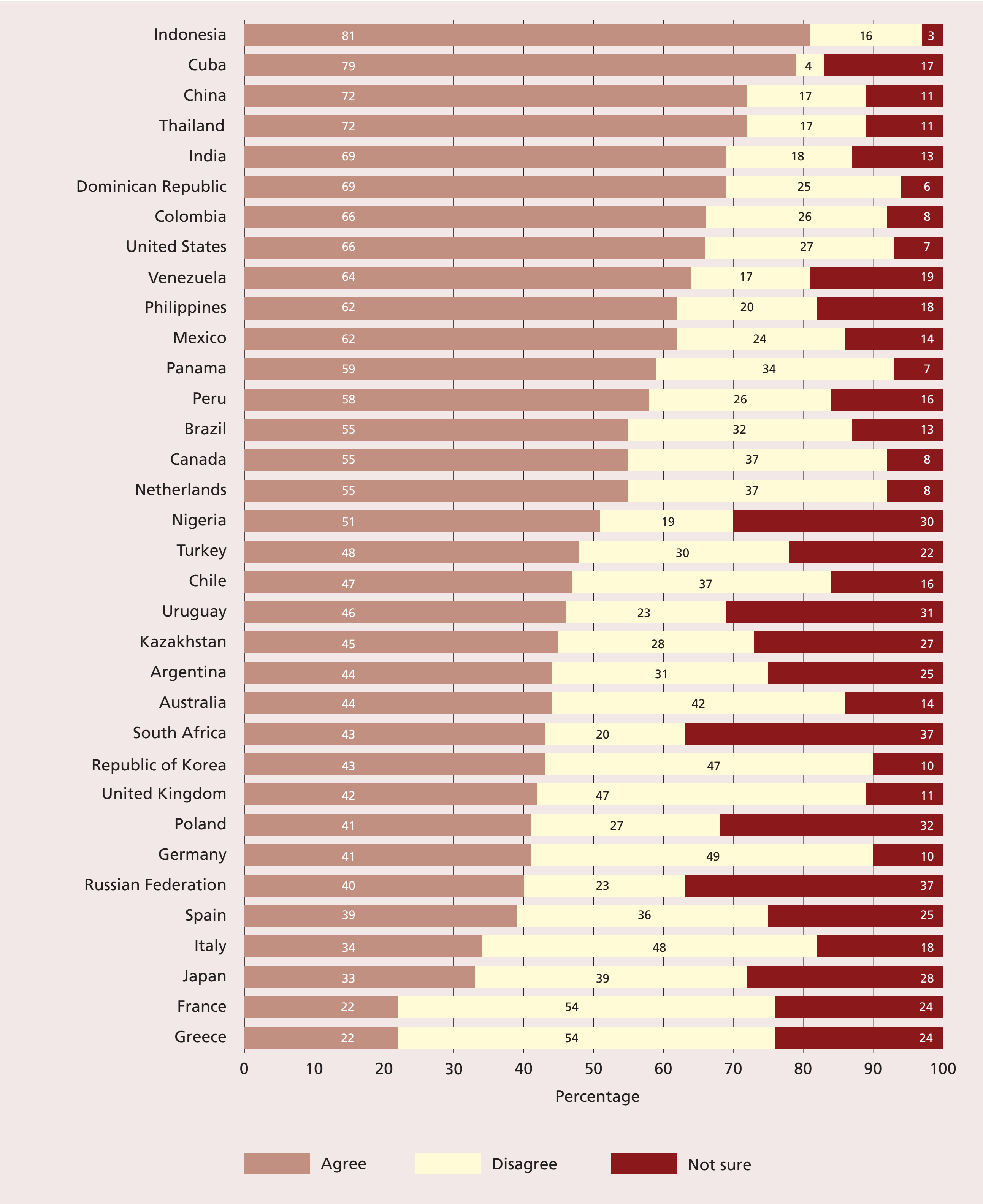
In general, people in developing countries were more likely to support the application of genetic engineering to reduce the use of chemical pesticides and herbicides. On average, three-fifths of respondents from non-OECD countries agreed with the statement compared with two-fifths in the OECD countries. This suggests that for people in poorer countries the potential benefits of biotechnology tend to weigh more heavily than the perceived risks, whereas the opposite is true for wealthier countries. The OECD countries with the highest rate of agreement tend to be those where genetically engineered crops are already grown: Canada, Mexico and the United States.

Support for different applications of biotechnology

In a second question, the Environics International (2000) study asked survey respondents whether they would support or oppose the use of biotechnology to develop each of eight different applications (Figure 11). Public support differs widely depending on the specific biotechnology application under consideration. Applications that address human health or environmental concerns are viewed more favourably than applications that increase agricultural productivity. Almost all respondents indicated that they would support the use of biotechnology to develop new human medicines, although 13 percent would oppose it. More than 70 percent supported the use of biotechnology to protect or repair the environment, for example crops that produce plastics, bacteria that clean up environmental wastes or crops that require fewer chemicals. Support for the development of more nutritious crops was also supported by a large majority (68 percent) of those surveyed.

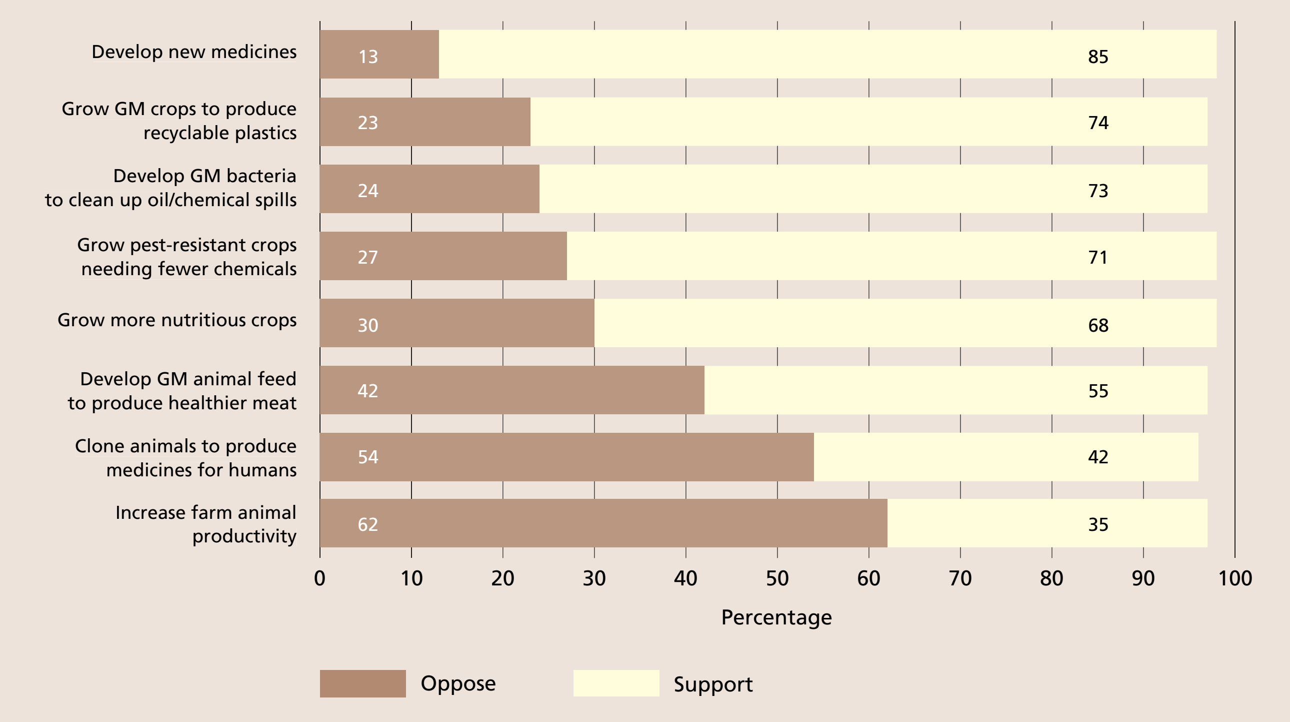
Biotechnology applications related to animals received considerably less support than crop or bacterial applications. Only a little over half of the respondents (55 percent) expressed support for genetically modified animal feed even when this resulted in healthier meat. The use of biotechnology to clone animals for medical research was opposed by 54 percent of those surveyed, and 62 percent opposed the genetic modification of animals to increase productivity. These results suggest that

FIGURE 10
The benefits of biotechnology outweigh the risks



Source: Environics International, 2000.

FIGURE 11
Do you support these biotechnology applications?



Source: Environics International, 2000.

people are less comfortable with animal biotechnology, perhaps because it involves more complex ethical issues. People appear more likely to accept animal biotechnology applications that embody some tangible benefit, such as for human health, whereas economic benefits such as improved productivity were less persuasive.

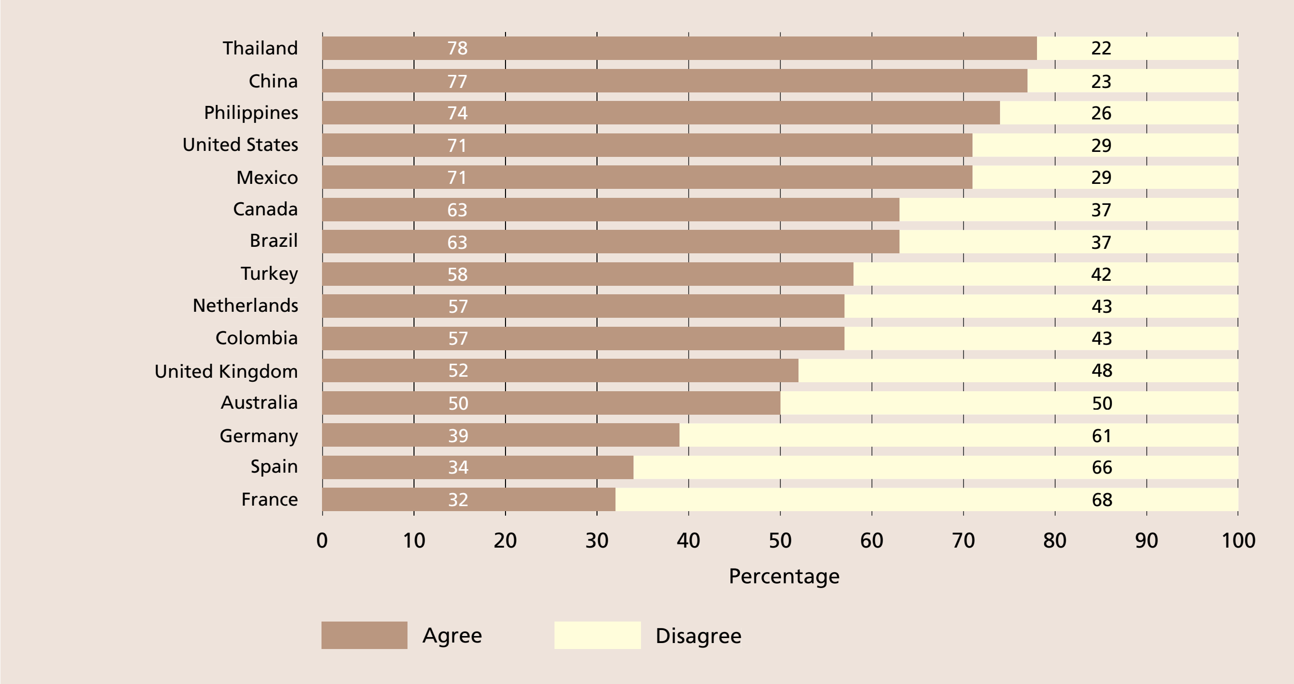
Personal expectations of biotechnology

In a set of follow-up questions, Environics International (2000) sought to understand some of the attitudes and concerns underlying public support or opposition to biotechnology. In 15 of the study countries, respondents who indicated that they had heard of biotechnology were asked to agree or disagree with the following statement:

> *Biotechnology will benefit people like me in the next five years.*

Almost 60 percent of the respondents to this question agreed that biotechnology would be beneficial (Figure 12). People from the Americas, Asia and Oceania were much more optimistic than Europeans that biotechnology would benefit them (no African countries were included in these follow-up questions). Two-thirds of the people from the Americas, Asia and Oceania held this view, compared with fewer than half of the Europeans. A similar divide was apparent by income level. Only a little more than half of the OECD respondents believed biotechnology would benefit them, whereas almost three-quarters of the people from non-OECD countries agreed with the statement. Countries where people were pessimistic about the potential of biotechnology to benefit them also tended to have fewer people who agreed that the benefits of genetically modified crops outweighed the risks. This finding corresponds with the higher levels of acceptance for biotechnology in the Americas, Asia and Oceania shown in Figure 10. It suggests that people who believe biotechnology will be personally beneficial to them are more likely to support its use.

FIGURE 12
Biotechnology will benefit people like me



Source: Environics International, 2000.

Moral and ethical concerns

In a second follow-up question people were asked to agree or disagree with the statement:

Modifying the genes of plants or animals is ethically and morally wrong.

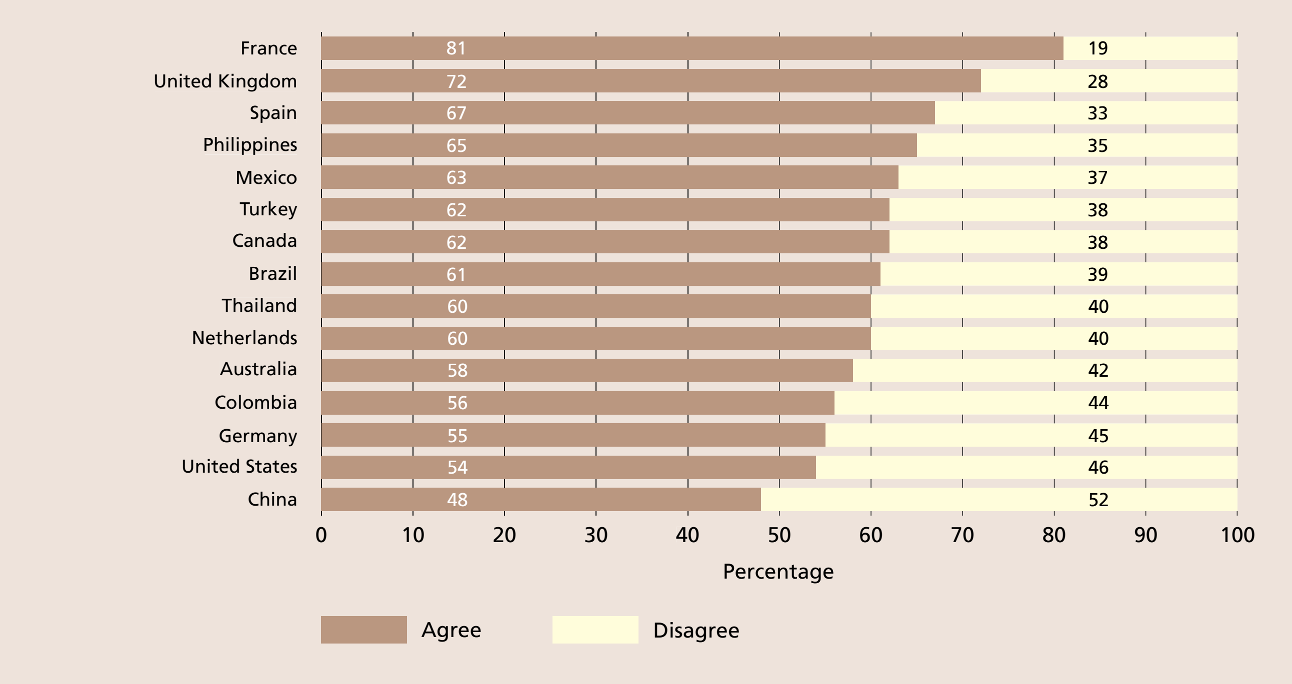
More than 60 percent of the respondents agreed with this statement, and the responses were more consistent across countries than for the other questions (Figure 13). More than half of the people surveyed in every country except China agreed that genetic modification of plants or animals was ethically and morally wrong. This result seems at odds with the generally high acceptance levels of plant biotechnology revealed in Figures 10 and 11, and may reflect the fact that the statement considered genetic modification of both animals and plants. As shown in Figure 11, people were less likely to accept any form of biotechnology that involved animals.

People were divided along regional and income lines in their ethical and moral judgements regarding genetic modification, with Europeans more likely to consider genetic modification ethically and morally wrong than people from the Americas, Asia and Oceania. OECD residents were also more likely than people from non-OECD countries to have ethical or moral reservations about genetic modification. The regional and income divisions are less sharp than for the other statements, but the overall pattern is similar. Countries where people consider genetic modification morally and ethically wrong also have fewer people who agree that the benefits of biotechnology exceed the risks or that the technology will be of benefit to them.

Consumer-oriented applications

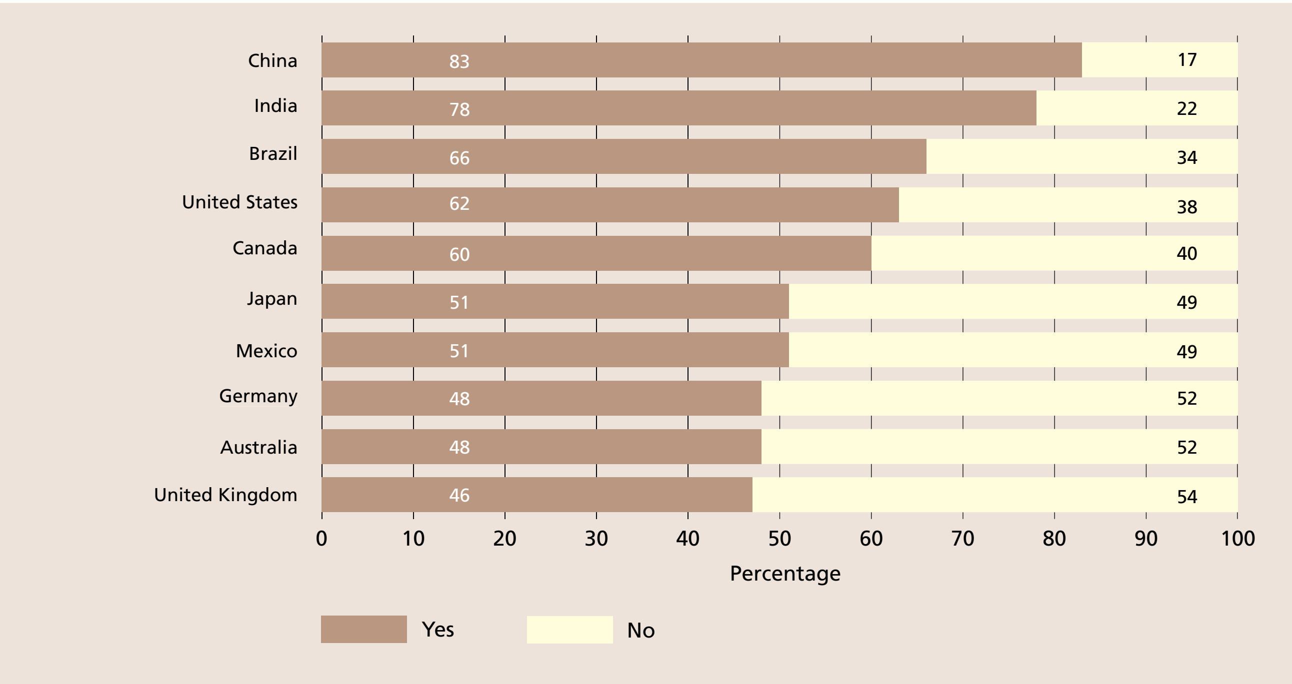
In a second study, Environics International (2001) explored whether products more beneficial to consumers would elicit a higher acceptance rate. They asked 10 000 consumers in ten countries whether they would buy food with GM ingredients if the resulting products were higher in nutrition (Figure 14). Respondents were given the option of continuing to buy the product or to stop buying it if they learned it was genetically modified in this way.

FIGURE 13
Modifying the genes of plants or animals is wrong



Source: Environics International, 2000.

FIGURE 14
Would you buy nutritionally enhanced foods?



Source: Environics International, 2001.

Almost 60 percent of all respondents indicated that they would buy nutritionally enhanced foods. European consumers were less willing than those from other regions, but the geographical differences seem to be less clear than for the other questions. Income level has a stronger relationship with willingness to buy nutritionally enhanced foods. More than 75 percent of consumers in China and India and 66 percent of those in Brazil indicated a willingness to buy more nutritious GM foods. Only a little more than half of consumers in the OECD countries indicated a willingness to buy, and a majority of consumers in Australia, Germany and the United Kingdom would not buy. These results suggest that although new GM crops that provide clear consumer benefits would be welcomed in many countries, they may not overcome consumer opposition in all countries.

Food labelling and biotechnology

Lack of societal and scientific consensus regarding modern agricultural biotechnology has led some to propose that products of this technology be labelled as a way to compromise and move forward. Labelling proponents argue that providing information on food packages will enable individual consumers to choose whether to accept or reject genetic engineering through their food purchasing decisions. Opponents argue that such labels would unfairly bias consumers against foods that have been determined to be safe to eat by national regulatory authorities. Although labelling appears to be a simple solution, it has caused complex debates within and among countries (Chapter 5).

Product versus process

It is generally agreed that genetically modified products must be labelled if they differ from conventional products in terms of their nutritional, organoleptic (i.e. flavour, appearance, texture) and functional properties. There is also agreement that foods that may cause allergic reactions as a result of genetic modification should carry a warning label, if they are marketed at all (FAO/WHO, 2001, section 4.2.2). In these circumstances the focus is on the end product and labelling is done to prevent misbranding and to warn consumers of possible risks (i.e. traditional reasons to label). Note, however, that Codex texts on food safety assessment of GMOs discourage the transfer of genes that would code for allergens (FAO/WHO, 2003e), and therefore such products are unlikely to be approved by national regulatory authorities.

Labelling a product because processes of biotechnology were used in producing the product has been suggested. The criteria for determining whether a product would be labelled if the end product had no discernible difference from the conventional product, contained no detectable traces of DNA, etc., is a topic of debate (FAO/WHO, 2003b).

Often the motivation for process-based labelling is to address social objectives such as offering consumers choices and protecting the environment. Labelling to inform consumers about a process is a relatively new way to use food labels and it is controversial.

Right to know versus need to know

Proponents of labelling of bioengineered foods believe that citizens have a right to know information about the processes used to produce a food. Few would disagree; however, opponents of labelling argue that information that is not essential to protect health and prevent fraud may lead to consumer confusion and could have detrimental effects.

Although there is scant experience regarding consumers' reactions to labelling of genetically engineered foods, there is concern within the food industry that labels would lead consumers to infer that the products were inferior to conventional products.

Research indicates that consumers' decisions about food purchases are influenced by various information sources (Frewer and Shepherd, 1994; Einsiedel, 1998; Knoppers and Mathios, 1998; Pew Initiative, 2002b; Tegene *et al.*, 2003); thus the impact of the food label could depend on the other messages that the public is receiving. The types of public information available regarding biotechnology vary in different countries and among different segments of the population, and thus generalizations about the impact of labelling are difficult to make.

Mandatory versus voluntary labelling

A number of countries have considered whether to require food producers to disclose that a food was produced through biotechnology. Some governments have enacted legislation making labelling mandatory (e.g. the European Union, Australia, China, Japan, Mexico, New Zealand and the Russian Federation).

Other countries reject this approach (e.g. Argentina, Brazil, Canada, South Africa and the United States). However, some are considering voluntary labelling for those producers wishing to provide this information to consumers.

Negative labelling – this product does not contain genetically engineered ingredients

It has been suggested that labels saying that a food does not contain products of biotechnology ("negative labelling") would give consumers the option of avoiding genetically engineered foods. This could encourage the development of niche markets for some producers, such as organic farmers.

Opponents of this approach believe that such labels would mislead consumers, causing them to infer that genetically engineered foods are inferior. Others argue that requiring a producer to prove that a product is not genetically modified places an unfair burden on small producers.

Technical, economic and political considerations

To be effective, labelling policies must be supported by standards, testing, certification and enforcement services (Golan, Kuchler and Mitchell, 2000). Labelling presents a number of challenges, which have not been resolved. These include the need to identify the most appropriate definitions and terms to be used in labelling, developing scientific techniques and systems for monitoring the presence of genetically engineered ingredients in foods and enacting the appropriate regulations to enforce a labelling policy.

All of the labelling options have costs that would be borne by food producers and governments initially and could lead to higher food prices and taxes for the public. Ethicists have argued that it would not be appropriate to impose these costs on all consumers because some people may not care about biotechnology (Thompson, 1997; Nuffield Council on Bioethics, 1999). Others argue that mandatory labelling is justified if a large proportion of the population wishes to have the information. Some consumers may be restricted in making food choices by low income or lack of alternative food choices, whereas others may be unable to understand food labels. Thus, labelling in itself may not fully reflect consumer preferences.

Labelling raises potential issues of unfair competition among food producers. In addition to the economic impact within countries, labelling could have an impact on international trade. Exporters of genetically engineered food products have objected to the mandatory labelling policies of importing countries, believing they are unjustified barriers to trade.

Resolution of the debate – Codex

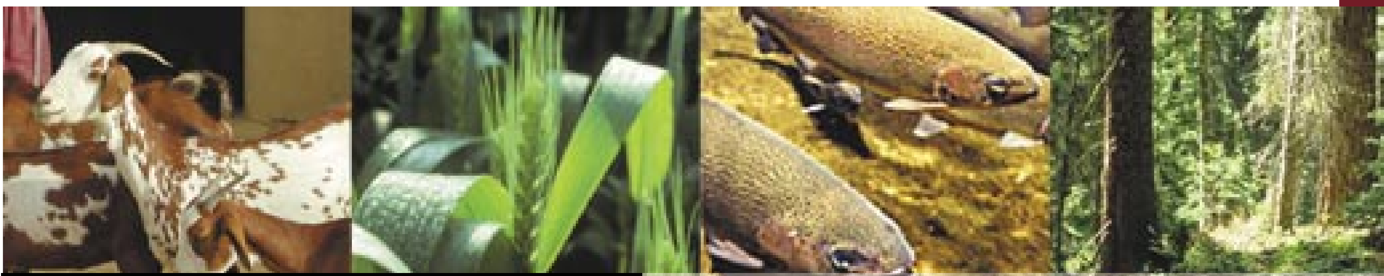
These issues have been the subject of deliberations in the Codex Alimentarius Commission's Committee on Food Labelling for several years. At the Codex Committee on Food Labelling meeting held in May 2003, a working group was established to address them.

Conclusions

Public attitudes towards biotechnology, particularly genetic engineering, are complex and nuanced. Relatively little internationally comparable research on public opinion has been performed, but the available findings reveal significant differences across and within regions. People from poorer countries are, in general, more likely to agree that the benefits of agricultural biotechnology exceed the risks, that it will be beneficial to them and that it is morally acceptable. People from the Americas, Asia and Oceania are far more optimistic about the future of biotechnology than are Africans and Europeans. There are exceptions to these simple patterns, and it is clear that many factors influence attitudes towards biotechnology.

It is apparent that few people express either complete support for or complete opposition to biotechnology. Most people appear to make subtle distinctions among techniques and applications according to a complex set of considerations. Among these considerations are the perceived usefulness of the innovation, its potential to cause or to alleviate harm to humans, animals and the environment, and its moral or ethical acceptability. People from all regions are generally more accepting of medical applications than agricultural ones, and more accepting of agricultural applications for plants than for animals. People are generally more accepting of innovations that provide tangible benefits to consumers or the environment than those aimed at increasing agricultural productivity. These subtle distinctions suggest that public attitudes towards agricultural biotechnology will change as new applications are developed and as more evidence becomes available on the socio-economic, environmental and food safety impacts. More internationally comparable research is needed to identify the multifaceted set of factors that influence people's attitudes towards biotechnology and to understand the ways in which those attitudes are evolving.

Labelling is being considered as a means to bridge differences in public attitudes towards biotechnology, particularly genetic engineering. Although this may seem a simple solution, the debate surrounding the merits and feasibility of labelling is complex. The issue touches on the fundamental rationale for food labelling and has implications for distributional equity, consumers' rights and international trade. Some argue that people have a right to know whether a product was produced through genetic engineering even if it does not differ in any discernible way from its conventional counterpart. Others argue that such labels would mislead consumers, implying a difference where none exists. There are further disagreements over the technical implementation of a labelling requirement and over who should bear the costs. There is currently no international consensus on this issue, although the Codex Alimentarius Commission continues to work towards agreed guidelines for food labelling.



Section **C**: Making biotechnology work for the poor

7. Research and research policy for the poor

Agricultural biotechnology holds enormous promise for addressing a range of technical challenges facing poor farmers in poor countries (Chapter 2). We know from the Green Revolution that agricultural research can stimulate sustainable economic growth in developing countries, but the paradigm for research and technology delivery that made the Green Revolution possible has broken down (Chapter 3). That system was explicitly designed to promote the development and international transfer of productivity-enhancing technologies to farmers in poor countries as free public goods. Global agricultural biotechnology research, by contrast, is dominated by the private sector, which focuses on crops and traits of importance for commercial farmers in large profitable markets.

The private sector has proven that it can deliver transgenic crops to poor farmers in poor countries when farmers are able to capitalize on products developed for commercial purposes elsewhere, as in the case of Bt cotton in Argentina, Mexico and South Africa, or when the public sector plays a pivotal role, as in China (Chapter 4). Who will develop biotechnology innovations for the majority of developing countries that are too small in terms of market potential to attract large private-sector investments and too weak in scientific capacity to develop their own innovations? How can the barriers to international technology transfer be reduced so that more countries can take advantage of technological innovations developed elsewhere? At present, no institutional infrastructure exists that possesses both the resources and the incentives to focus on delivering a stream of biotechnology innovations to farmers in these countries.

This chapter explores some strategies for better focusing public- and private-sector research on the problems of the poor and for increasing the likelihood that farmers in developing countries can capture spillover benefits from technologies developed in other countries. Many of the same recommendations can both focus more research on the poor and help ensure they have access to the resulting technologies. In a world in which the science required to generate improved technologies is becoming increasingly complex and expensive, the level of collaboration among public institutions, and between public and private institutions, must increase (Pray and Naseem, 2003b).

Promoting access to biotechnology applications

How can more farmers in more countries gain access to the technologies that are emerging from the Gene Revolution? A number of factors inhibit the international transfer of new agricultural technologies and prevent farmers from taking advantage of the public and private agricultural research that is already taking place around the world. The following are among the most important steps that need to be taken by individual countries and the international community to facilitate the safe transfer of technologies. Many of these steps will also help attract public and private investment in research on the problems of the poor by reducing the costs of technology development and expanding the likely market for technological innovations. Countries and the international community need to:

- establish transparent, predictable science-based regulatory procedures and harmonize regulatory procedures, where appropriate, at regional or global levels;
- establish appropriate intellectual property rights (IPR) protections to ensure that developers can earn an adequate return on investment;
- strengthen national plant-breeding programmes and seed systems; and
- promote the development of efficient agricultural input and output markets and reduce trade barriers on agricultural technologies.

Regulatory requirements

Absent or poorly functioning biosafety regulatory systems constitute a major barrier to the development and diffusion of transgenic crops by private companies and the public sector. Private companies will neither invest in transgenic crop research tailored to the needs of a particular country nor attempt to commercialize an existing product there unless a transparent, science-based regulatory system is in place.

Regulatory requirements add substantial costs to the research and development process for transgenic crops. Biotechnology firms typically expect to spend about $10 million for each new transgenic product to develop the portfolio of health, environmental and agricultural biosafety information required by the regulatory authorities of a typical industrialized country. These costs are justified, of course, if the process results in scientifically sound decisions that command the confidence of the public and technology developers. However, if a technology company has to spend millions of dollars on biosafety research that unnecessarily duplicates research done elsewhere or in an effort to satisfy continuously changing requirements, it will be less interested in investing in the country.

An expensive, unpredictable and opaque biosafety regulatory regime is even more restrictive for public research than private research, because public institutes have considerably less money to finance the research trials required to meet regulatory requirements. If the regulatory process is very time-consuming and expensive, large transnational companies may be the only institutions that will be able to afford to commercialize a transgenic crop.

Governments must find ways to rationalize their regulatory requirements and fund the necessary environmental and human health safety trials if they want to attract privately developed technologies or to promote public biotechnology research to help the poor. Harmonizing biosafety regulatory measures, where appropriate, can reduce unnecessary duplication and lower barriers to the transfer of new conventional and transgenic plant varieties between developing countries. This would also allow private firms or public-sector institutions to reach a wider market for the products of their research. If biosafety standards were harmonized on a regional basis, countries with well-developed biotechnology research and development programmes could supply technology to neighbouring countries with similar agro-ecological conditions. The number of countries with functioning biosafety committees is increasing, but until there is some type of regional harmonization and sharing of biosafety information, the regulatory transaction costs present insurmountable entry barriers for a substantial number of countries.

Intellectual property rights

A second obstacle to the international transfer of agricultural biotechnology is the difficulty of protecting IPR. The experience to date with IPR protection for transgenic soybeans, maize and cotton worldwide is mixed: enforcement has been strong in some countries, weak in others and uncertain in most. Many people are concerned that IPR protections on biotechnology and plant varieties will limit farmers' access to seeds by granting private corporations monopoly control of vital genetic resources and research techniques. Although this has not been a widespread problem thus far (Chapter 4), governments have an ongoing responsibility to ensure that private companies cannot exploit their monopoly position by charging excessive prices for their products. At the same time, the essential role of IPR protection in stimulating research and technology development is clear. Firms must be able to appropriate enough of the economic returns from the technology to justify their investment (Chapter 3). Countries need to find the appropriate balance that provides enough IPR protection to encourage private-sector research and technology development while protecting farmers from monopoly exploitation.

The large transnational firms realize that resource-poor farmers growing subsistence crops in small countries are unlikely to become commercial buyers for their products, and IPR protection alone is unlikely to stimulate them to enter these markets. Enhanced IPR protection in some of the larger developing countries could provide a powerful incentive for private firms (transnational and local) to conduct more research on the problems of the poor and to adapt and commercialize products developed elsewhere. Large firms have worked with local companies to adapt patented products for smaller markets; for example, the Bt gene developed by Monsanto has been incorporated into cotton for small farmers in Africa and Asia and recently into white maize in South Africa. Private firms have been willing to donate and/or commercialize technology that can benefit the poor, and they would probably do so more widely if regulatory barriers could be overcome.

National plant-breeding programmes

The countries that will take the most advantage of transgenic crops developed elsewhere are those that have strong national plant-breeding programmes. National plant-breeding capacity, with or without the help of biotechnology, is necessary to incorporate imported transgenic innovations into cultivars that are appropriately adapted for local conditions. Breeding programmes manipulate genetic resources through combining genes from two or more parents. Selection and evaluation procedures are applied to help identify the best individuals for local agro-ecological conditions. Seed production follows to increase the availability of the best materials, allowing them to be released to farmers as commercial varieties. The International Treaty on Plant Genetic Resources for Food and Agriculture wisely stresses the role of plant-breeding programmes and seed production systems to deliver research results to poor farmers. Any investment in biotechnology, before ensuring these components are in place, has a high probability of failure.

Efficient markets for agricultural technologies

A fourth obstacle inhibiting the international transfer of transgenic crop innovations, and possibly the most difficult to remedy, is the absence of functioning seed markets in most countries for most crops. With the exception of maize, cotton and vegetables in a few countries, seed markets are very poorly developed, making it difficult to deliver modern varieties, including transgenic varieties, to farmers. Liberalizing input markets and eliminating government monopolies can increase the potential size of the market for biotechnology innovations. This was an important factor in increasing private agricultural research in Asia (Pray and Fuglie, 2000) and still may be important in the seed market in some countries because seed markets are often the last markets to be liberalized (Gisselquist, Nash and Pray, 2002). Many countries still need government intervention to create the necessary physical infrastructure, such as transportation and communication, and institutional infrastructure, such as law and order and enforceable contract law, that are required for markets to work.

Promoting public- and private-sector research for the poor

There is a strong consensus among economists regarding what type of research is needed for biotechnology to contribute to reducing poverty and which institutions should do it (Lipton, 2001; Byerlee and Fischer, 2002; Naylor *et al*., 2002; Pingali and Traxler, 2002). There is increasing debate about how to stimulate public biotechnology and conventional research on poor peoples' crops in developing countries, particularly in the current climate of scepticism about the benefits of biotechnology, declining donor interest in funding agricultural research and low agricultural prices. The tools for encouraging private biotechnology research are better known, albeit more controversial. Many of the steps described above to reduce barriers impeding the international transfer of biotechnology innovations will encourage more private-sector and public-sector research for the poor, but additional steps are also needed. The remainder of this chapter outlines a research agenda to address the problems of the poor and explores ways of stimulating public and private research in these areas, including public–private partnerships to ensure researchers in developing countries can gain access to research tools and genes that will assist the poor.

This section outlines a pro-poor research agenda and explores some strategies for focusing more research on the problems of the poor and ensuring that developing countries have access to emerging technologies.

Transgenic crop research priorities for the poor

The crops that should be the focus of a pro-poor research agenda are the basic staple foods of the poor: rice, wheat, white maize, cassava and millets (Naylor *et al*., 2002). The traits needed to improve the condition of the poor farmers include increasing yield potential, increasing stability of yields through resistance to biotic and abiotic stress, and enhancing the ability to grow more nutritious subsistence crops under difficult conditions, such as drought and salinity (Lipton, 2001). Insect resistance of crops can be a valuable trait for poor farmers, especially where other control methods are not available or where hazardous chemical controls can be reduced or replaced (Chapter 4). Herbicide tolerance, on the other hand, may not be so important in land-scarce, labour-abundant economies where hand-weeding is a source of employment. Finally, small farmers who have limited access to land, machinery and chemical inputs should be targeted.

One of the most efficient ways to reduce micronutrient malnutrition of the poor is through enhancing the micronutrient content of basic food grains (Graham, Welch and Bouis, 2001). In some cases this can be done through conventional breeding. In fact, the first new varieties for addressing micronutrient malnutrition are likely to be high-iron rice produced through conventional breeding. However, for some characteristics, such as enhancing rice with vitamin A and other micronutrients, transgenic crops can be an important part of the answer (Box 26).

In addition to the development of crops to meet the needs of the poor, consumers and governments in developing countries are starting to demand more research on the environmental and health impacts of transgenic crops. Many developing countries have little local scientific expertise to help policy-makers sort out the conflicting claims surrounding transgenic crops. Environmental concerns, in particular, should be evaluated under different agro-ecological conditions and thus require locally managed research (Chapter 5). Without such research, consumer and environmental opposition may prevent transgenic crops from being approved for commercial use in developing countries.

Priority activities can be established by preparing a detailed inventory of all prospective biotechnology products characterized by crop and by agro-ecological environment, followed by an *ex-ante* assessment of the potential impact of each of these technologies on the productivity and livelihoods of subsistence producers. Such an assessment would lead to the identification of a set of products already in the research pipeline with high pro-poor potential that public–private partnerships could be built around.

Stimulating public agricultural research for the poor

Stimulating public research to address the problems of the poor is constrained by the difficulty of obtaining reliable, long-term funding for agricultural research. Public agricultural research programmes in many developing countries and the International Agricultural Research Centres (IARCs) are facing declining financial support. Furthermore, in the competition for declining funds, the poor are often neglected. Almost by definition, the poor do not have well-

BOX 26
Can biotechnology address the needs of poor farmers? The role of participatory agricultural research

The potential of biotechnology, particularly genetic engineering, to meet the needs of resource-poor farmers is immense. The problem as articulated by Lipton (2001) is that the potential is "locked into a system where it is not used for such purposes, and where a few large firms are competitively bound to protect their investment by means that, at present, threaten public research". For the public and private sectors to work effectively together to address the problems of the poor, it is desirable that the needs of the farmers are properly accounted for through participatory research. In participatory agricultural research, farmers are considered to be active participants who may lead the research process and whose ideas and views influence its outcome, rather than passive bystanders or objects of research (Thro and Spillane, 2000). This is important because farmers' perceptions and preferences for particular technologies will influence ultimate adoption. Participatory agricultural research is considered as integral to the overall research strategy and priority setting rather than as a substitute.

Thro and Spillane (2000) suggest several reasons why participatory research related to transgenics is needed. First, collaborative and farmer-led decisions about whether to use genetic engineering require that farmers and researchers understand each other's vocabulary and typologies and have at least a rudimentary grasp of each other's expertise. Second, given the biosafety and environmental concerns surrounding transgenic products, it is important that farmers be aware of these issues. If farmers are not aware of these concerns, scientists may implicitly assume that they have no preference for one technological approach over another. Third, the ability of genetic engineering to allow the development of entirely new traits and plant types requires researchers to understand and identify new options, some of which may be identified only through participatory research with farmers.

To date, very few priority-setting exercises with resource-poor farmers have led to the implementation of biotechnology-assisted research. One area in which biotechnology tools could be particularly useful is in plant breeding. Tools such as marker-assisted selection, inducible promoters, controllable male sterility, inducible apomixis and visual markers provide greater flexibility in local breeding and increase the range of varietal options from which farmers can choose. Pingali, Rozelle and Gerpacio (2001) developed a methodology for eliciting farmers' preferences using an experimental voting method. The methodology allows for quantitative estimates of preferences and the socio-economic determinants of adoption. They find that farmers have strong preferences for certain technologies, in particular those that conserve scarce factors of production or maximize farm income, but are ambivalent about others.

For participatory biotechnology research to be successful, certain conditions need to be met. Perhaps the most important of these are that the information on proposed technologies is conveyed clearly and that there is sustained communication among biotechnologists, plant breeders and farmers. Although participatory research is focused on the improvement of local livelihoods, one must not lose sight of the fact that basic and applied research is still useful and needed. Even basic research must carefully address the issues raised by farmers, but it may call for greater collaboration between social scientists and biological scientists to translate the needs of farmers into priorities for basic research.

organized representatives who can lobby for their interests when government research resources are being allocated. Yet there are NGOs, charities, foundations and some donors that are specifically focused on the poor. These groups need to be mobilized to support agricultural research – conventional and biotechnology – on poor peoples' problems. Programmes such as participatory breeding (Box 26) that involve citizens in decision-making on the technology can help direct public research to the issues that are important for poor farmers.

More studies are needed on the economic, environmental and health impacts of biotechnology and alternative technologies, particularly for the poor. Such research can help answer some of the remaining scientific questions about the safety and efficiency of transgenic crops and can help people compare them with existing alternative production systems. Programmes that educate farmers and consumers about the potential benefits and risks of biotechnology can empower people to make informed choices. In addition, transparent biosafety regulations can help ensure that appropriate regulatory decisions are made and can reassure people that they are protected from unacceptable risks.

Although there is a need for countries to develop their national agricultural research capacity in order to evaluate and adapt biotechnology innovations, it is neither necessary nor economically rational for every developing country to establish capacity in the more advanced biotechnology research approaches. The capacity needed to use technology is different from the capacity needed to generate technology. Countries should strategically evaluate their research capacity and focus their efforts on ensuring at least a minimum capacity to evaluate biotechnologies and adapt imported technologies. Certainly, there are numerous small countries that lack the capacity for even this type of research.

There may be some potential for the larger developing countries – Brazil, China, India and South Africa – to become regional suppliers of biotechnology research for smaller countries. The advantages of clustering research efforts for countries with similar agroclimatic conditions are obvious, and each of these countries has significant research capacity in both basic and agricultural science. Of these countries, however, only China has experience with public-sector delivery of a transgenic product; in fact, Brazil and India have only recently approved GMOs for commercial use. There is no indication that the public sector in any other country will soon become a major player, and no other country has yet benefited from biotechnology discoveries made in China.

The lack of institutional arrangements for sharing intellectual property is a large hurdle to be overcome in the transfer of technologies from one national public-sector institution to another. Contrary to the pace at which private-sector companies now share intellectual property, there is scant experience anywhere in the world where public-sector institutions have the flexibility or the motivation to achieve such exchanges. This implies that a radically new mindset and new institutional arrangements would need to emerge before the sharing of intellectual property could become sufficiently routine to allow smaller countries to depend on their large public-sector neighbours to supply useful research outputs. At present, except for germplasm being shared within the CGIAR networks, there is very little cross-border sharing of technology between public-sector institutions, probably because of a lack of incentives for public officials to negotiate such arrangements, but also because of the implicit competition among countries in international commodity markets.

Stimulating private research to focus on the poor

Despite the evidence from the field trial data that first-generation research of private firms did not concentrate on the crops, traits and countries needed to make a difference for the poor, there is a considerable amount of biotechnology research in the private sector that is producing knowledge, research tools, genes and GM varieties that can be useful to the poor in developing countries. Such research includes the rice genome research financed by Monsanto and Syngenta and the functional genomics research on rice that will identify what genes and groups of genes do in rice and other grains. Research of this type will probably require public-sector plant breeding to produce actual varieties for the poor, but with some changes in appropriability the private sector could play a role. This section explores some options that could increase the incentives for private-sector biotechnology and plant breeding firms to pursue research and product development more specifically targeted to the poor.

One scenario under which the private sector could become a more reliable source of biotechnology innovations for developing countries is that in which the large-market developing countries, i.e. Brazil, China, India and South Africa, became more "GMO friendly". If these countries were to achieve stable regulatory and IPR regimes and GMO products were accepted by consumers in these large markets, the private sector would very likely make substantial research and development (R&D) investments in developing GMO products for their significant agricultural problems. These four countries have a combined seed market of about $5 billion. Products developed for these markets would then become available for neighbouring countries that have mounted the necessary biosafety regulatory and IPR enforcement capacity. Once the private sector had developed useful products for farmers in the tropical and semi-tropical regions of these countries, they could begin marketing them in other countries with similar agro-ecological conditions.

In addition to the measures needed to promote access to the technological innovations discussed above, governments can take other steps to encourage private-sector investment in agricultural research for the poor. These steps would reduce the costs of research and technology development, increase the potential market size for biotechnological innovations and provide direct incentives to address the problems of the poor.

Governments can reduce the cost of research by using public-sector research universities that produce highly skilled scientists. Cooperative research programmes with universities in the developed world could enable universities in developing countries to gain access to knowledge, research tools and germplasm for research on problems of the poor.

Easing restrictions on foreign direct investment can attract more resources for research and technology transfer, and easing restrictions on trade in inputs required for research, such as chemicals, can reduce research costs. Small local firms may also need government assistance in gaining access to proprietary technology.

In addition to providing commercial incentives for private research to assist the poor, governments can show goodwill by providing positive publicity, perhaps in the form of prizes to firms that develop and spread technology to the poor. The introduction of tax incentives or better investment opportunities for private firms that invest in the needs of the poor are also possibilities. In the United States and elsewhere, private foundations and charitable organizations such as the Rockefeller Foundation have been established and have grown in part because of tax incentives.

Another possibility for providing incentives to the private sector to conduct more research is a major prize programme for agricultural technology that reduces poverty or food insecurity (Lipton, 2001). Such a competition would focus on crops of major importance to the poor; both public and private institutes could compete and the monetary prizes would be large enough to make it worthwhile for firms to compete. The prize money could come from a combination of government and private foundations. The $200 million programme funded by the Bill and Melinda Gates Foundation for research on diseases that cause millions of deaths in developing countries that was recently announced offers a possible model for funding such a programme.[10]

Public–private partnerships

In many cases, public- and private-sector entities could work together more effectively so that each focuses on its area of expertise and capitalizes on the contributions of the other. The question that needs to be asked is whether incentives exist, or can be created, for public/private-sector partnerships that allow the public sector to use and adapt

[10] See their Web site at http://www.gatesfoundation.org.

technologies developed by the private sector for the problems faced by the poor. Can licensing agreements be designed that will allow private-sector technologies to be licensed to the public sector for use in relating to problems of the poor? Pingali and Traxler (2002) suggest that the public sector may have to purchase the right to use private-sector technology on behalf of the poor.

A recent review of the options for accessing biotechnology highlighted the possibilities for partnerships between public NARS, local seed companies, global companies and the CGIAR (Byerlee and Fischer, 2002). This section summarizes some of the key points of the review and then focuses specifically on the few successful cases of transferring biotechnology to farmers and developing new technologies.

Public-sector access to patented biotechnology genes and tools

There are at least five ways in which public research institutes or local firms can obtain patented biotechnology genes and tools. First, they can simply use the technology without seeking permission from the owner. For technologies that are easily copied or fully revealed in patent disclosures, it may be efficient and legal for scientists to do this if no patent on the invention has been filed in the country or if the technologies are excluded from patent coverage. Many important biotechnology tools are widely patented, however, especially in countries with well-developed NARS, and products made using proprietary tools would not be exportable to markets where they are patented. Nevertheless, where patents are not in force and for goods that are not traded, this could be an option.

A second option is to purchase the technology. The public sector may have the most success in purchasing these technologies from universities or small private companies. For example, a consortium of public research institutes in Asia, led by IRRI, purchased the rights to a Bt gene from a small Japanese biotechnology company (Byerlee and Fischer, 2002). However, few key technologies will be available for purchase.

Material transfer and licensing agreements are a third possibility. Material transfer agreements (MTAs) define the conditions for research use and leave the conditions for commercialization to a future date. Initially this method is cheaper, but there is the risk that the company that undertakes the research will not be allowed to commercialize the technology developed later. Licensing agreements, on the other hand, specify the conditions for commercialization of a technology, the payments and the sharing of benefits. They are probably the most common mechanism for technology and knowledge transfer (although in some countries the first option, used without permission, is more frequent).

Alliances and joint ventures are the fourth possibility. In joint ventures both parties agree to provide specific assets and to share the benefits; joint venture contracts typically include MTAs and licensing agreements on technology. There is a growing consensus that partnerships between the public and private sectors will be needed to use biotechnology effectively for the poor in developing countries (Byerlee and Fischer, 2002; Pingali and Traxler, 2002).

A fifth possibility is that certain technologies could be donated for humanitarian use. Many technologies could be used to meet the needs of the poor, but the markets are too small to be profitable for large private firms. Firms might be willing to donate their technologies, but they would want to retain their patent rights for use in places where they can be profitable. If markets can be segmented such that the public sector has the rights to use any technology that is provided by the firm or is jointly developed to serve the resource-poor farmers, and the private sector is given the rights to sell the technology to commercial farmers, then the two groups can have the basis for a partnership. A number of agreements of this type (which segment the world by crop, by region, by country income level and by trade status) have been negotiated, notably for Golden Rice, but none has yet been tested to see how they work. The experience with Bt cotton and HT soybeans suggests that it will be very difficult to segment markets by certain traits effectively.

Elements of successful partnerships

To negotiate successful partnerships, partners have to identify their goals, value their assets,

TABLE 11
Values and assets of public and private sectors in agri-biotechnology research

	Public sector	Private sector
Performance measure	Social benefits including share to poor producers and consumers	Profits
National-level organizations	Public NARS	Local seed companies
Key assets	Local diverse germplasm	Local knowledge
	Local knowledge	Breeding programmes and infrastructure
	Breeding and evaluation programmes and associated infrastructure	Seed delivery system
	Access to delivery system including extension	Marketing network
	Upstream capacity in Type I NARS	
	Positive public image	
Regional and global-level organizations	CGIAR International Centres	Global life science companies
Key assets	Diverse germplasm	Biotechnology tools, genes, knowledge
	Breeding programmes and associated infrastructure	Access to capital markets
	Global germplasm exchange and evaluation networks	Economies of market size
	Economies of market size	Skills in dealing with regulatory agencies
	Upstream capacity in a few centres	Possible negative public image
	Generally positive public image	

Source: Byerlee and Fischer, 2002.

identify complementarities and identify the potential to segment markets for the different partners (Byerlee and Fischer, 2002). Partners must also recognize their different cultures and values – public research attempts to maximize social benefits whereas private firms maximize profits. To reach a partnership agreement requires negotiations.

Table 11 identifies the research assets of the different groups that might be partners in a public–private joint venture. The strongest assets of public research institutions tend to be their germplasm, variety assessment infrastructure and (in the stronger NARS) the capacity to conduct upstream research. They generally also have a positive public image, which can be an important asset. Private local firms have local knowledge, breeding programmes, and seed marketing and delivery systems. Transnational companies have the biotechnology, access to capital markets, economies of market size and skills in dealing with regulatory agencies. The CGIAR institutes have germplasm, breeding programmes, global germplasm exchange, etc. Assets such as germplasm and genes are clearly complementary assets. For example, Embrapa (Brazilian Agricultural Research Corporation) has used its soybean germplasm assets to development a partnership with Monsanto to obtain Roundup Ready® genes and plant transformation technology. Together they have produced a series of Roundup Ready® soybean varieties tailored for the Brazilian market.

Examples of public–private partnerships

Public- and private-sector institutions are experimenting with many different types of research partnerships and technology transfer arrangements. Only a few have been successful in developing useful technologies and these have been less successful in passing the technology on to the poor – primarily because of regulatory or other legal challenges that have delayed the commercial release of the products. Some of the more successful joint ventures are summarized below, together with some of the characteristics that they have in common.

The most successful examples of a joint venture that has been able to spread biotechnology to poor farmers are the Ji Dai and An Dai seed companies in China. Ji Dai is a joint venture between two companies based in the United States (Monsanto and D&PL) and the Hebei Provincial Seed Company in China. An Dai is a joint venture between the same United States companies and the Anhui Provincial Seed Company in China. These joint venture contracts provide that Monsanto supplies the Bt gene and D&PL provides the cotton varieties while Ji Dai and An Dai provide the variety testing, seed multiplication, and seed distribution networks in their respective provinces and beyond. Ji Dai and An Dai sales of Bt cotton seed now total about 2 000 tonnes and the total area planted with their Bt varieties – including farmer-saved seeds and unauthorized sales by other seed companies – is over 1 million ha. All of their seed sales go to small farmers (under 2 ha), although not always to poor farmers. Approximately two-thirds of the households that adopted Bt cotton had per capita annual incomes of less than $360, converted at official exchange rates (see Chapter 4 for an analysis of the economic impacts of Bt cotton in China).

The incentives for participating in these joint ventures were money and perhaps some publicity. The United States companies hoped that the provincial government-owned seed companies would provide them with the political weight they needed to ensure that their GM cotton varieties were approved by the Biosafety Committee and put into commercial production. They also hoped that the provincial seed companies would provide them with some market power so that they could charge high enough prices to make a profit. Their first hope seems to have been fulfilled as they were able to obtain approval for their varieties in some (but not all) provinces. However, their second hope of gaining market power appears to have been more difficult to fulfil. The provincial seed companies were also looking for new money-making opportunities. Previously, cotton seed had not been a commercially interesting enterprise, but introducing the Bt gene greatly increased the value of the cotton seed that contained it. They could now make money from the seed. In addition, the provincial authorities were able to revive an important cash crop that had been declining as a result of severe pest attacks.

Another project that successfully targets poor farmers is Bt cotton adoption by small farmers in Makhathini Flats in South Africa. This land is located in an area that forms part of a government irrigation project where all of the growers are small African farmers and many do not have access to irrigation. Monsanto, D&PL and Clark[11] (the major cotton purchasing and ginning company in South Africa) made special investments in technical personnel and other resources to teach small farmers how to use Bt cotton profitably. They also worked with the local government research station and government extension service, and provided credit for inputs and labour costs of cotton production. The money for this credit in the early years came from the government Land Bank and the interest rate was fixed by the government. Virtually all cotton farmers in Makhathini Flats have adopted Bt cotton and most appear to have made substantial gains in income as a result of it (see Chapter 4 for an analysis of the economic impacts of Bt cotton in South Africa).

The incentive for private South African firms to participate in this programme seems to derive from a combination of political and social goals. The South African Government is putting pressure on all private firms to undertake more social welfare projects. The success of Bt cotton in Makhathini Flats has provided excellent publicity for the companies involved. It is highly unlikely that the increased income that the project makes from the sales of Bt seed would cover all the research and extension resources that the firms have invested. However, what they are getting is valuable experience in developing strategies to work with poor small farmers in Africa.

[11] Clark is owned by the farmer cooperative OTK. Clark, in turn, owns Vunisa, which deals directly with the farmers in Makhathini Flats.

Examples of successful technology development

Brazil provides a number of examples of collaboration in research and technology development that may be replicable in other countries with large public and private research capacity. The joint venture between Embrapa and Monsanto on transgenic soybeans, mentioned above, is an example of collaborative applied research. Embrapa provides the varieties and some plant transformation technology and Monsanto provides the genes and most of the transformation technology. Monsanto plans to sell the GM soybeans through its dealer system and Embrapa will receive royalties from the sales. A portion of the sales will go back to a research fund for sustainable soybean production.

A second type of collaborative research occurs when private firms or cooperatives in developing countries hire individual scientists or rent laboratories at universities or government institutions in a collaborative effort. For example, the Cooperative of Cane, Sugar and Ethanol Producers of the State of São Paolo (COPERSUCAR) developed transgenic, virus-resistant sugar-cane varieties by hiring researchers at the University of São Paolo at Campinas, the University of Minnesota and Texas A&M University to perform specific parts of the research that they could not do in-house. As a result of this collaboration, COPERSUCAR has developed virus-resistant sugar cane that has been tested by its biosafety regulators and is ready for production when officially approved (Pray, 2001).

Several of the smaller but more advanced NARS have had successful partnerships with large firms to develop new technology. Egypt provides one useful example of a public–private joint venture in research (Byerlee and Fischer, 2002). In this case the Agricultural Genetic Engineering Research Institute (AGERI), an Egyptian public research institute, and Pioneer Hi-Bred jointly developed a new Bt gene. In the collaboration, the Egyptian public system gains access to expertise to develop the local strain of Bt (the innovation) and to educate its staff. The private sector partner pays the legal costs of patenting the invention and has access to the new Bt strain for use in markets outside Egypt.

Another example is the Monsanto and the Kenya Agricultural Research Institute collaboration on virus-resistant sweet potatoes, which began more than a decade ago. Monsanto provided the gene and trained a Kenyan scientist in biotechnology. Virus-resistant varieties are now in field trials and the commercial release of this technology is possible in the next few years.

Promising examples of collaboration

For smaller countries with less well-established NARS, the international research centres of the CGIAR system or regional intellectual property holding companies may be the only source of transgenic technology. The international centres have entered into a limited number of joint ventures to secure access to specific technologies for the poor. Examples include: the Kenya, CIMMYT and Syngenta project to develop Bt maize for eastern Africa; IRRI's collaboration with European government laboratories and Syngenta to develop Golden Rice; and the international collaboration on rice genomics led by IRRI (Byerlee and Fischer, 2002).

Recently, several new multicountry programmes to obtain access to technology for the poor have been initiated. The African Agricultural Technology Foundation (AATF) is a non-profit corporation funded initially by the Rockefeller Foundation. It will license and hold technology from the major biotechnology firms with a humanitarian use licence and subsequently provide the technology free to scientists in poor African countries.[12] In addition, the Australian-based institute, CAMBIA (Center for the Application of Molecular Biology to International Agriculture), is making information about patented technology more readily available and developing non-proprietary technologies for biotechnology researchers in poor countries.[13] Another recent initiative is the proposed IP Clearing-House programme in the United States, which has the goal of making intellectual property from universities and government research institutes more readily available. This programme seeks to design a toolbox of

[12] See their Web site at http://www2.merid.org/AATF.
[13] See their Web site at http://www.cambia.org.

biotechnologies for public-sector researchers in industrialized and developing countries at an affordable rate (Graff and Zilberman, 2001).

Elements of successful collaboration

The joint ventures that have actually transferred technology or produced new technology have had several characteristics. First, both parties had something substantial to gain from the collaboration. The gains do not have to be financial, although financial gains may provide the strongest incentives for long-term collaboration. Second, governments had the political will and ability to negotiate with private firms; in many countries this can be very difficult because of mistrust of the private sector and inexperience. Third, both parties had to make long-term, sustained investments of time and money; research and the development of new products always takes longer than expected. Fourth, joint ventures required a budgetary commitment from the public-sector partners, which in the cases in Egypt and Kenya were financed by foreign donors. Fifth, for weaker national systems some type of broker such as the International Service for the Acquisition of Agri-biotech Applications (ISAAA) or a CGIAR institute may be important in matching the technology with the needs of the country. The number and variety of joint ventures is growing rapidly. A systematic study into what makes successful joint ventures work could be extremely useful at this time.

Conclusions

The dominance of the private sector in agricultural biotechnology research and commercialization has raised a number of concerns about who will benefit from biotechnology. The available empirical evidence on the impact of transgenic crop research in developing countries shows that resource-poor farmers can benefit from GM crops if the crops address their needs and if they have access. This chapter suggests three groups of policies that would provide more technology to the poor.

First, policies are needed to encourage private investment in research and marketing biotechnology applications that meet the needs of the poor. These include commercial incentives such as more efficient biosafety regulations and stronger IPRs, government incentives for research for the poor, and financial prizes for research and technology for the poor.

Second, more public research is needed on the problems of the poor. Sustainable public biotechnology research for the poor requires the development of groups that will lobby for the poor. With leadership from local antipoverty groups and donors who are committed to reducing poverty, effective local support for public research to reduce poverty might be built. International support for the IARC biotechnology research programmes is also essential and we hope can be strengthened when the IARC biotechnology programmes start to prove their usefulness through the development of new technology for farmers.

Third, public–private joint ventures are needed to make efficient use of the propriety technology developed by the private and public sectors in industrialized countries. Governments can take a number of actions to facilitate such joint ventures.

Fourth, investments have to be stimulated first in strengthening national capacity to develop varieties (plant breeding) and seed systems; only then will investments in biotechnologies produce the expected results for poor farmers.

These steps could be helpful, but they are no guarantee that the resulting technologies would ever reach the poor. Given that conventional technologies available today have not yet reached the poorest farmers' fields, the new biotechnologies may not fare any better. Are there any policy interventions that will improve the situation? Identifying factors that impede small farmers' access to and use of technology continues to be an issue that the development community must deal with. Investments in biotechnology research capacity for the public sector will only be worthwhile if the current difficulties in delivering conventional technologies to subsistence farmers can be reversed.

8. Capacity building for biotechnology in food and agriculture

The case studies examined in Chapter 4 revealed that small farmers in developing countries can benefit from transgenic crops, as they have done in the past from other productivity-enhancing technological innovations. However, these gains are not automatic. Nations need adequate policy and institutional/technical capacity to deliver them and farmers need access to suitable innovations on affordable terms. Unlike the Green Revolution, which was based on an explicit strategy of the international transfer of improved technology as a free public good, almost all transgenic crop varieties and most other agricultural biotechnology innovations are being created and disseminated by the private sector. Chapter 7 addressed some strategies to increase public and private research and partnerships that focus on developing technologies to address the problems of the poor.

However, several barriers stand in the way of biotechnology reaching resource-poor farmers and especially the poor countries that could benefit substantially from these innovations. Safe and informed use of biotechnology requires adequate capacity for policy formulation, agricultural research, financial resources and marketing channels, as well as a framework for intellectual property rights and the capacity to handle the regulatory matters regarding food safety, human and livestock health, and environmental safety. Although biotechnology is evolving rapidly and is poised to play a fundamental role in further agricultural and economic development, there remains a large gap in most developing countries and especially among the least developed in their ability to assess their specific circumstances, meet their commitments and benefit from the opportunities that may arise from biotechnology. There is often a policy vacuum and inadequate capability to comply with the international instruments relating to biotechnology.

The most frequent problems encountered by developing countries and countries in transition are:

- insufficient capacity within ministries and their institutions to analyse options, set priorities for investment and formulate policies for national deployment of biotechnology in food and agriculture that support national development goals;
- limited technical, legal and administrative capability to establish and implement regulatory procedures, including biosafety, risk assessment and intellectual property rights, protection of indigenous knowledge and local resources, and communication to raise public acceptance of new technologies; and
- limited resources and capabilities to design, establish and operate infrastructures needed to generate, adapt, transfer and regulate biotechnology applications in food and agriculture, including enabling environments for furthering collaboration between the public and the private sectors.

National capacities in agricultural biotechnology

Strong and dynamic capacity at the technical, institutional and management levels is the most important requisite for successful and sustainable application of biotechnology in food and agriculture. However, developing countries and countries with economies in transition vary widely in their capacity to manage agricultural biotechnology effectively. In particular, they span a wide spectrum in their capacities for agricultural biotechnology research and regulatory management, including intellectual property rights.

In recent years, there has been a steady development of agricultural biotechnology capacity in several of the larger countries, notably in Brazil, China and India, where human and financial resources allocated to biotechnology R&D are relatively high and experience in the commercialization of biotechnology products is growing. Where governments have made substantial investments in public-sector agricultural biotechnology research in the developing world, several common themes emerge. First, they have gradually built a strong scientific base in agricultural research and biotechnology. Their national research institutes are encouraged to be actively involved in bilateral and international collaborative research programmes in diverse fields of agricultural biotechnology. Second, in their national policies they have specifically identified science and technology, and biotechnology in particular, as an important engine of economic growth both for agriculture and for the health sector. Third, their public agricultural research programmes have had substantial success in promoting rapid agricultural growth. These countries have seen the explosive growth of information technology and its contributions to their economies and hope for similar growth through medical and agricultural biotechnology.

Towards the middle of the spectrum are those developing countries that are now beginning to incorporate biotechnology increasingly in their agricultural research programmes, for instance Egypt and Indonesia. These countries generally have moderately strong conventional agricultural research capacity and are developing strong biotechnology capacity in several areas.

Further towards the other end of the spectrum are those countries that have not advanced far in direct application of the tools and techniques, except for applications of simpler techniques such as micropropagation and tissue culture. Again, these countries have several things in common. Research efforts are less advanced and often several related programmes are scattered over a wide range of products and institutes. The programmes are often heavily dependent on donor funding and run the risk of drying up as soon as the funds are exhausted. Furthermore, the marketing and management of biotechnology products are virtually absent, as is the critical mass required to raise public awareness. In many instances, governments do not accord sufficient priority to agricultural research, and policies to support agricultural research in general and agricultural biotechnology in particular are either lacking or not implemented. Because advancements in agricultural biotechnology are severely constrained in these countries, potential payoffs from biotechnology research and development programmes remain low.

The recently launched FAO-BioDeC[14] is a database providing updated baseline information on the state-of-the-art biotechnology products and techniques that are in use or in the pipeline in developing countries and those with economies in transition. Currently, the database includes about 2 000 entries from 70 countries and focuses on research, testing and commercialization of specific crop technologies and products in developing countries. Although the data are limited, they do give an overview of the different stages of adoption and development of these technologies in different countries and regions and offer the possibility of identifying gaps, as well as potential partners for joint programmes in areas of common interest.

In addition to research capacity, countries also vary widely in their capacity to regulate biotechnology. The spectrum ranges from those that have well-developed IPR regimes and food safety and environmental safety regulatory procedures to those that have little or no capacity to manage these issues.

International capacity-building activities in agricultural biotechnology

A number of private, governmental, non-governmental and intergovernmental

[14] Available at http://www.fao.org/biotech/inventory_admin/dep/default.asp.

organizations are involved in one or more ways in capacity-building programmes in biotechnology. The focus areas include policy development assistance, research, technology transfer, biosafety measures and related regulatory oversight, development of associated legislation and creating public awareness. A wide range of activities are carried out for strengthening the policy, institutional and technical level of competence. Agencies involved in such initiatives are the International Service for National Agricultural Research (ISNAR) Biotechnology Service (IBS), the International Centre for Genetic Engineering and Biotechnology (ICGEB), the ISAAA, the Global Environment Facility (GEF), the United Nations Industrial Development Organization (UNIDO), USAID and many more. Although there is some overlap between the services offered by these organizations, each fulfils a certain function different to the others or places more emphasis on certain areas. There is no global information on the entire range of activities being carried out in agricultural biotechnology; however, the Biosafety Capacity Building database of the Biosafety Clearing-House[15] provides a good overview of the various project activities being carried out in this area around the world.

FAO role and assistance to member countries

FAO provides global fora to facilitate dialogue, and is a repository of statistical information. FAO can play a pivotal role in assisting Member Governments with science-based guidance on this subject as well as in standard-setting. Some of the key activities focused on biotechnology are as follows.

- Promoting international standard-setting bodies. FAO supports several agreements that have an important bearing on agricultural applications of biotechnology, particularly in relation to the WTO SPS and Technical Barriers to Trade (TBT) Agreements. These include the IPPC and the Codex Alimentarius Commission, and the International Treaty on Plant Genetic Resources for Food and Agriculture, which covers conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of benefits derived from their use.
- Capacity building through technical assistance and training. FAO is assisting member countries in building their legal and regulatory frameworks in harmony with international obligations; training and strengthening facilities and institutions for the appropriate and safe utilization of biotechnology for food and agriculture; developing their national legislations in this area; and building the capacity for participating in international negotiations on biotechnology to optimize national benefits. See Box 27 with regard to Bangladesh.
- Information dissemination. FAO provides objective, science-based information on agricultural biotechnology, collecting, analysing and disseminating information in five languages, including through the corporate Web site[16] and publications. This activity covers all aspects of biotechnology in food and agriculture, taking into consideration that member countries and their citizens need balanced and unbiased information on the potential benefits and risks of biotechnology.

Challenges in capacity building for agricultural biotechnology

Despite the range of capacity-building activities being carried out, much more needs to be done. The challenges faced are on a scale unlike those of other technological revolutions, including the Green Revolution in the 1960s and 1970s. For instance, any application of biotechnology requires a framework for safety including that of the environment and of human and animal health. There is a demand for equitable distribution of the benefits

[15] Available at http://bch.biodiv.org/Pilot/CapacityBuilding/SearchOpportunities.aspx.

[16] Available at http://www.fao.org/biotech/index.asp?lang=en.

BOX 27
FAO and capacity building in agricultural biotechnology in Bangladesh

In 2002, FAO and the United Nations Development Programme (UNDP) conducted an assessment of the status of biotechnology application in Bangladesh. Based on this assessment, the Government of Bangladesh formulated a National Programme for Biotechnology (NPB), which aims to utilize biotechnology as an important complementary route to fight food insecurity and poverty, two pressing problems of the nation. The NPB will promote awareness at all levels; establish and implement appropriate policies, strategies and partnerships; strengthen investment, institutional and market support; and undertake focused and integrated biotechnological research and development. The key components of the NPB are:

- **National Policy for Biotechnology, its implementation and governance**. Address the technological and enabling aspects of biotechnology application. A National Taskforce for Sustainable Biotechnological Development (NTSBD), under the chairmanship of the Principal Secretary of the Office of the Prime Minister, will ensure that the policy is being effectively implemented. The NTSBD will provide transparent and efficient governance and build the required confidence in all stakeholders.
- **Enabling regulatory measures.** Legislative and regulatory frameworks for IPR, TRIPS, biosafety, and access to and negotiations on new technologies and products, consistent with the national needs and farmers' aspirations and rights, will be established and strengthened. Effective containment facilities, risk analysis, other biosafety-related capacities and human resources to manage regulatory aspects have high priority. The introduction, evaluation and commercialization of "Golden BR 29" (an elite Bangladeshi rice variety transformed at IRRI for high beta-carotene content) will be showcased to strengthen the national capacity in instituting and handling regulatory measures.
- **Institutional strengthening.** Biotechnological R&D institutions in the country will be strengthened by equipping them with state-of-the-art infrastructure, centralized facilities, suitably trained human resources, information and communication facilities and by fostering public–private partnerships. The capacity of NTSBD will be augmented for priority-setting, system-based decision-making, handling of issues in a disaggregated manner, cementing research–extension–farmer–market links and for generating and allocating resources.
- **Biotechnology programmes.** The NPB, following effective monitoring and evaluation, will focus on ecotechnologies towards an evergreen revolution, especially addressing the problems of small farmers. The following areas have been prioritized: production and distribution of *in-vitro*-cultured propagules, molecular characterization of genetic resources, diagnostics and recombinant vaccine production, biocontrol of pests and diseases, production and commercialization of quality (fish) fingerlings, development of transgenics for resistance to biotic and abiotic stresses, nutritional and other quality attributes, and molecular marker-assisted selection.
- **Three developments to help Bangladesh realize its goal.** (a) For the first time, Bangladesh has created a budget line for biotechnology in its national budget; (b) in order to ensure high efficiency and interdepartmental cooperation and to avoid wasteful duplication of effort, the NTSBD is being chaired by the Principal Secretary of the Office of the Prime Minister; and (c) UNDP and other donors and international organizations have shown considerable interest in funding the new initiative.

from the genetic resources utilized for biotechnology. In addition, it is important to develop consensus within society on the use of biotechnology-based products through full and transparent participation of all stakeholders in decision-making. Some of the major challenges in adoption of biotechnology include:

- ensuring resources to cover the high costs of inputs and development;
- building an enabling environment for the promotion of biotechnology;
- integrating biotechnology with conventional research programmes;
- addressing corporate control, market power and distributional implications;
- ensuring consumer protection and acceptance; and
- enhancing the sustainability of biotechnology programmes.

These factors, either directly or indirectly, affect capacity building, retention of personnel, and the balance between public- and private-sector capabilities. Although not exclusive to biotechnology, the initial costs of developing these technologies may increase the difficulties. Developing countries need to avoid the trap of dependence and unsustainability in their biotechnology programmes. Government policies should establish mechanisms to encourage both public- and private-sector investment and participation in agricultural biotechnology. Public- and private-sector research should be consciously complementary and not competitive. The policy framework should not only promote the safe use of biotechnology but also ensure that policies are not a deterrent to investment by the private sector and to collaboration with external partners. In many developing countries such progressive institutional and organizational reforms are hampered by the absence of appropriate policies or their appropriate implementation.

Next steps

Recognizing the constraints, there is a conscious need to take a sustained, holistic, multistakeholder, participatory approach to realize the potential benefits of agricultural biotechnology. In developing countries, there is a greater need to ensure not just capacity creation but also its retention and enhancement. Capacity-building activities have to be carried out at all levels: to raise the awareness of policy- and decision-makers, to initiate necessary legal and regulatory frameworks, to enhance technical and regulatory capacity, and to revamp institutions if necessary. More importantly, there is a need for continuous assessment and deployment of competent human resources and institutional capacity so that, as biotechnology advances, the tools for its safe use are constantly evaluated, upgraded and applied. It appears to be a daunting task, but through a firm commitment and partnerships it can be achieved.

9. Conclusions: meeting the needs of the poor

One of the main messages emerging from this year's *State of Food and Agriculture* report is that biotechnology is capable of benefiting small, resource-poor farmers. The key question is how this scientific potential can be brought to bear on agricultural problems of developing-country producers. Biotechnology holds great promise as a new tool in the scientific toolkit for generating applied agricultural technologies, but it is not a panacea.

Although the evidence suggests that biotechnology is relevant to all areas of agriculture, the research and farm-level applications – with some exceptions primarily in the plant sector – are taking place primarily in developed countries. The challenge at present is to design an innovation system that focuses this potential on the problems of developing countries.

Agricultural production systems in developing countries are complex and diverse. Many producers are small-scale and resource-poor, and for such producers some biotechnology innovations may be inappropriate. For example, animal reproductive technologies such as artificial insemination or embryo transfer that are quite common in North America and Europe require capital infrastructure beyond the reach of the scale and scope of their farms. Transgenic crops, by contrast, may be relatively easy for farmers to adopt because the technology is embodied in the seed – rendering it the most scale-neutral and easily transferable form of agricultural technology. Modern biotechnology must be incorporated into agricultural research and development programmes that begin with breeding and improved management, not as stand-alone technologies.

A second important message of this issue of *The State of Food and Agriculture* is that some transgenic crops, especially insect-resistant cotton, are yielding significant economic gains to small farmers as well as important social and environmental benefits through the changing use of agricultural chemicals. The evidence to date suggests that small farmers as well as large farmers can benefit from the adoption of transgenic crops targeted towards insect resistance.

Even though transgenic crops have been delivered through the private sector in most cases, the benefits have been widely distributed among industry, farmers and consumers. This suggests that the monopoly position engendered by intellectual property protection does not automatically lead to excessive industry profits. The Bt cotton results in Argentina demonstrate that the balance between the intellectual property rights of technology suppliers and the financial means of farmers has a crucial impact on adoption of the products and hence on the level and distribution of benefits. The case of China clearly illustrates that public-sector involvement in research and development and in the delivery of transgenic cotton can help ensure that poor farmers have access to the new technologies and that their share of the economic benefits is adequate.

Overall, it is the producers and consumers who are reaping the largest share of the economic benefits of transgenic crops, not the companies that develop and market them. Research evidence from Argentina, China, Mexico and South Africa suggests that small farmers have had no more difficulty than larger farmers in adopting the new technologies. In some cases, transgenic crops seem to simplify the management process in ways that favour smaller farmers. Further research needs to focus on policies and incentive structures that ensure that these gains are sustained as larger numbers of farmers adopt the technologies. Time and more carefully designed studies are required to determine what the level and distribution of benefits from transgenic crops will be.

A third message is that the changing locus of agricultural research from the public sector to the private transnational sector has important implications for the kinds of products that are being developed, how those products are commercialized and who receives the benefits. Private-sector research naturally focuses on the crops and traits of commercial interest to farmers in higher-income countries where markets for agricultural inputs are robust and profitable.

Although private-sector agricultural research expenditures seem overwhelmingly large, the reality is that they are focused very narrowly on the development of biotechnology-related plant varieties, and even that only for a very small number of crops. A large part of the private-sector investment is concentrated on just four crops: cotton, maize, canola and soybean. Private-sector investment in the world's two most important food crops, rice and wheat, is insignificant in comparison.

Moreover, all of the private-sector investment is targeted towards the commercial production sector in the developed world, with some spillover benefits flowing to the commercial sector in the developing world. The public sector, with its increasingly meagre budget, is left to take care of the research and technology needs of the subsistence farming sector, as well as being the only source of supply for conventionally bred seed as well as crop and resource management technologies.

Agricultural public goods, such as crops and traits of importance to subsistence farmers in marginal production environments, are of little interest to large transnational companies. The data on transgenic crop research show that the needs of resource-poor smallholders are being neglected, and the data on commercialization are even more dramatic. One of the lessons of the Green Revolution is that agricultural technology can be transferred internationally, especially to countries that have sufficient national agricultural research capacity to adapt the high-yielding cultivars developed by the international public sector for local production environments.

So how will farmers in developing countries be able to capture economic spillover benefits from the transgenic crops developed and commercialized by the private sector? Private-sector investments in genomics and genetic engineering could be potentially useful in addressing the problems faced by poor farmers, particularly those in marginal environments. Knowledge generated through genomics, for example, could have enormous potential in advancing the search for drought-tolerant crops in the tropics.

The question that needs to be asked is whether incentives exist, or can be created, for public–private sector partnerships that allow the public sector to use and adapt technologies developed by the private sector for the problems faced by the poor. How can licensing agreements be designed that will allow private-sector technologies to be licensed to the public sector for use on problems of the poor? Research presented in this report suggests that the public sector may have to purchase the right to use private-sector technology on behalf of the poor.

A fourth message from this report is that biotechnology is not a panacea, but a resource that can be useful when combined with adaptive research capacity. Regulatory regimes matter. Biosafety processes need to be in place. Countries that lack biosafety protocols or the capacity to implement them in a transparent, predictable and trusted way may not have access to the new technologies. Where crops have not been cleared through biosafety risk assessments that take into consideration local agro-ecological conditions, a greater risk of harmful environmental consequences exists. Additionally, unauthorized varieties may not provide farmers with the expected level of pest control, leading to continued need for chemical pesticides and a greater risk of the development of pest resistance.

A final message is that the environmental effects in terms of pesticide reduction can be positive. In the case of Bt cotton, the environmental outcomes have been strongly positive. In virtually all instances, insecticide use on Bt cotton is significantly lower than on conventional varieties. Furthermore, for herbicide-tolerant soybeans, glyphosate has been substituted for more toxic and persistent herbicides, and reduced tillage has accompanied herbicide-tolerant soybeans and cotton in many cases. Negative environmental consequences, although meriting continued monitoring, have not been documented in any setting where transgenic crops have been deployed to date.

So how can the Gene Revolution reach those left behind? First, by overcoming production constraints that are intractable with conventional breeding, biotechnology can speed up conventional breeding programmes and provide farmers with disease-free planting materials. Second, biotechnology can develop crops that resist pests and diseases, replacing toxic chemicals that harm the environment and human health. Third, biotechnology can develop diagnostic tools and vaccines that help control devastating animal diseases. Finally, biotechnology can improve the nutritional quality of staple foods such as rice and cassava and create new products for health and industrial uses.

The problem is that biotechnology cannot overcome the gaps in infrastructure, regulation, markets, seed systems and extension services that hinder the delivery of agricultural technologies to poor farmers in remote areas. Neither can it overcome the institutional failures, market failures and policy failures that hinder all efforts to promote agricultural and rural development in many countries. A great deal needs to be done so that developing-country producers are empowered to make their own decisions regarding these technologies for their own benefit.

Given that technologies that are on the shelf today (generated by conventional research methods) have not yet reached the poorest farmers' fields, there is no guarantee that the new biotechnologies will fare any better. Identifying small farmers' constraints to technology access and use continues to be an issue that the development community must address. Investments in biotechnology research capacity for the public sector will only be worthwhile if the current difficulties in delivering conventional technologies to subsistence farmers can be reversed.

The six main lessons for ensuring that the potential benefits of agricultural biotechnology reach the poor areas are as follows:

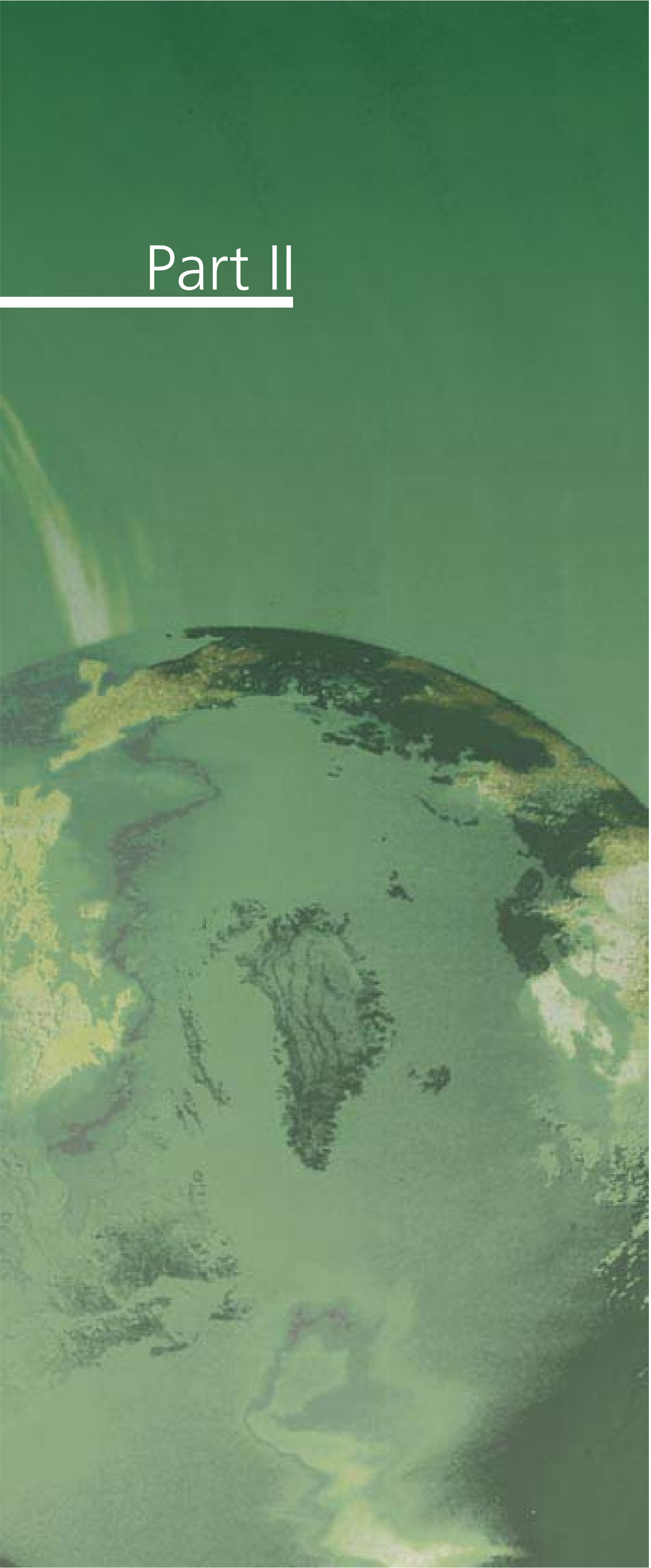
- Biotechnology – including genetic engineering – can benefit the poor when appropriate innovations are developed and when poor farmers in poor countries have access to them on profitable terms. So far these conditions are only being met in a handful of developing countries.
- Biotechnology should be part of an integrated and comprehensive agricultural research and development programme that gives priority to the problems of the poor. Biotechnology is not a substitute for research in other areas such as plant breeding, integrated pest and nutrient management and livestock breeding, feeding and management systems.
- The public sector in developing and developed countries, donors and the international research centres should direct more resources to agricultural research, including biotechnology. Public-sector research is necessary to address the public goods that the private sector would naturally overlook.
- Governments should provide incentives and an enabling environment for private-sector agricultural biotechnology research, development and deployment. Public–private partnerships and other innovative strategies to mobilize research efforts for the poor should be encouraged.
- Regulatory procedures should be strengthened and rationalized to ensure that the environment and public health are protected and that the process is transparent, predictable and science-based. Appropriate regulation is essential to command the trust of both consumers and producers, but duplicative or obstructionist regulation is costly and should be avoided.
- Capacity building for agricultural research and regulatory issues related to biotechnology should be a priority for the international community. FAO has proposed a major new programme to ensure that developing countries have the knowledge and skills necessary to make their own decisions regarding the use of biotechnology.

Part II

WORLD AND REGIONAL REVIEW

Facts and figures

Part II



1. TRENDS IN UNDERNOURISHMENT

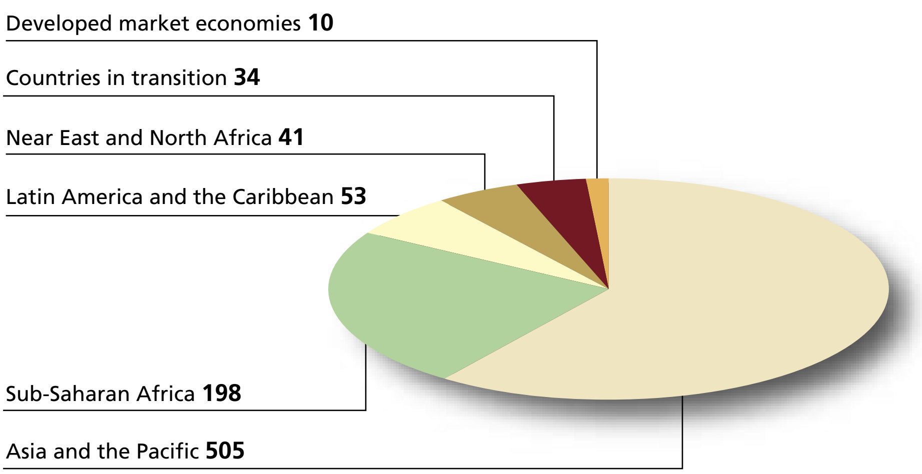
- FAO estimates the number of undernourished people in the world at 842 million: 798 million in the developing countries, 34 million in the countries in transition and 10 million in the developed countries.

- More than half of the total numbers of undernourished (60 percent) are found in Asia and the Pacific followed by sub-Saharan Africa, which accounts for 24 percent of the total (Figure 15).

- The picture is different in terms of the proportion of the population that is undernourished in the different developing country regions (Figure 16). By far the highest incidence of undernourishment is found in sub-Saharan Africa, where FAO estimates that 33 percent of the population is undernourished. This is significantly higher than the 16 percent undernourished estimated for Asia and the Pacific and the 10 percent estimated for both Latin America and the Caribbean and the Near East and North Africa.

- Over the past two decades, progress has been made in reducing undernourishment in the developing countries. The incidence of undernourishment has declined from 28 percent of the population two decades ago to 17 percent according to data from 1999–2001. However, as a result of population growth, the decline in absolute numbers has been slower. In addition, the decline was far more pronounced in the course of the 1980s, but appears to have slowed down in the 1990s.

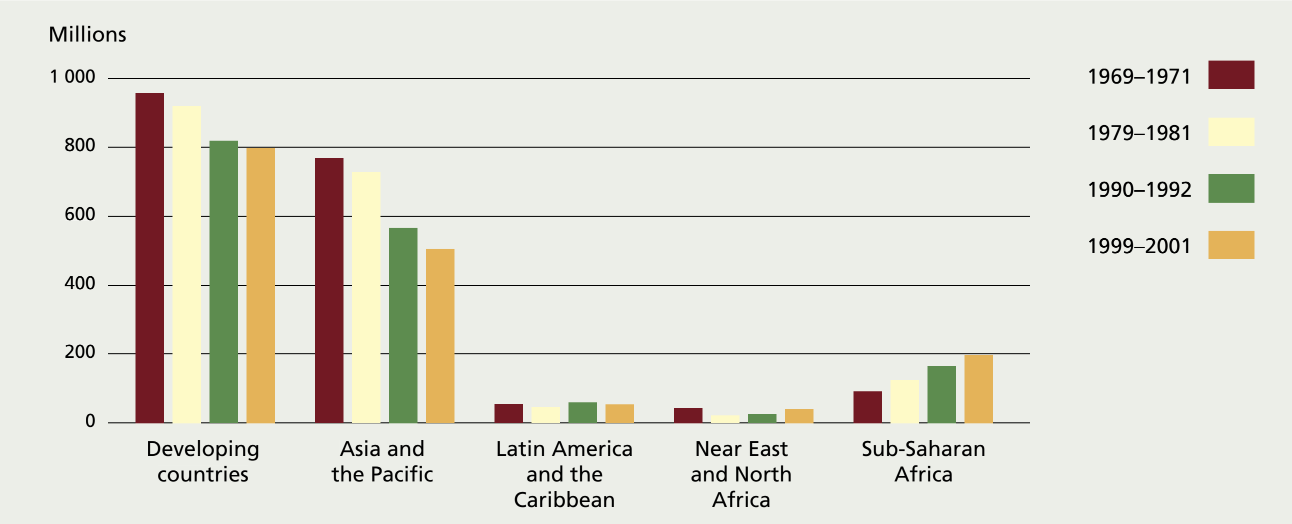
FIGURE 15
Undernourished population by region, 1999–2001 (millions)



Note: the figures in this graphic do not add up to the total of 842 million, due to rounding. *Source:* FAO.

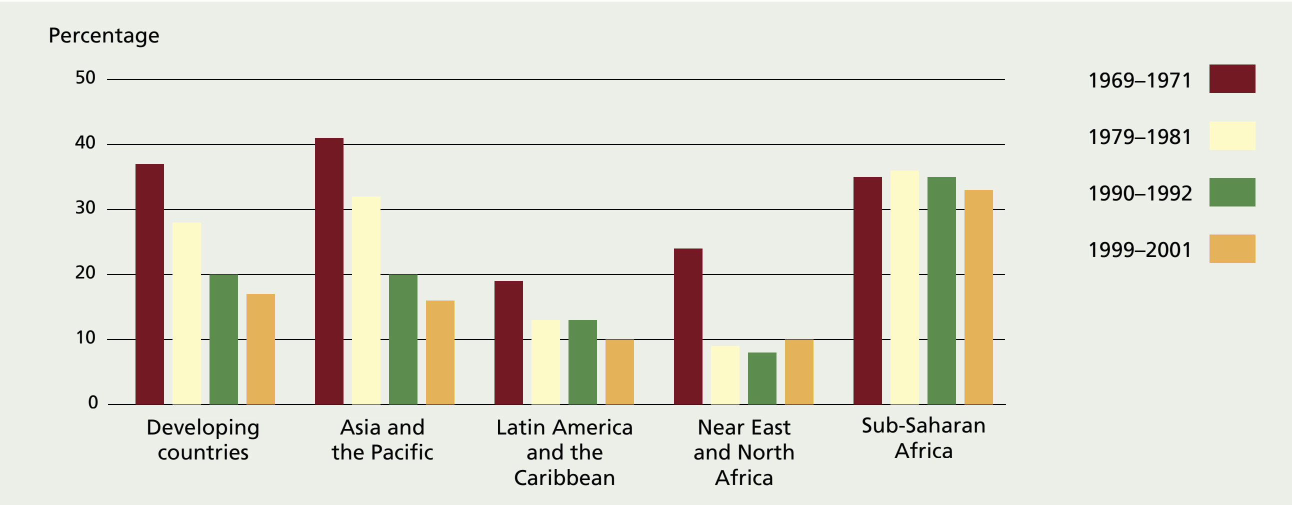
- Most of the improvement has been concentrated in Asia and the Pacific, which halved the incidence of undernourishment over the past two decades (Figure 17). In sub-Saharan Africa and Latin America, the very limited reduction in the percentage incidence of undernourishment has been more than counterbalanced by population growth, resulting in an increase in absolute numbers of undernourished. In the Near East and North Africa the percentage incidence of undernourishment in 1999–2001 stood at about the same level as two decades earlier.

FIGURE 16
Number of undernourished people in developing countries, by region



Source: FAO.

FIGURE 17
Percentage of population undernourished in developing countries, by region



Source: FAO.

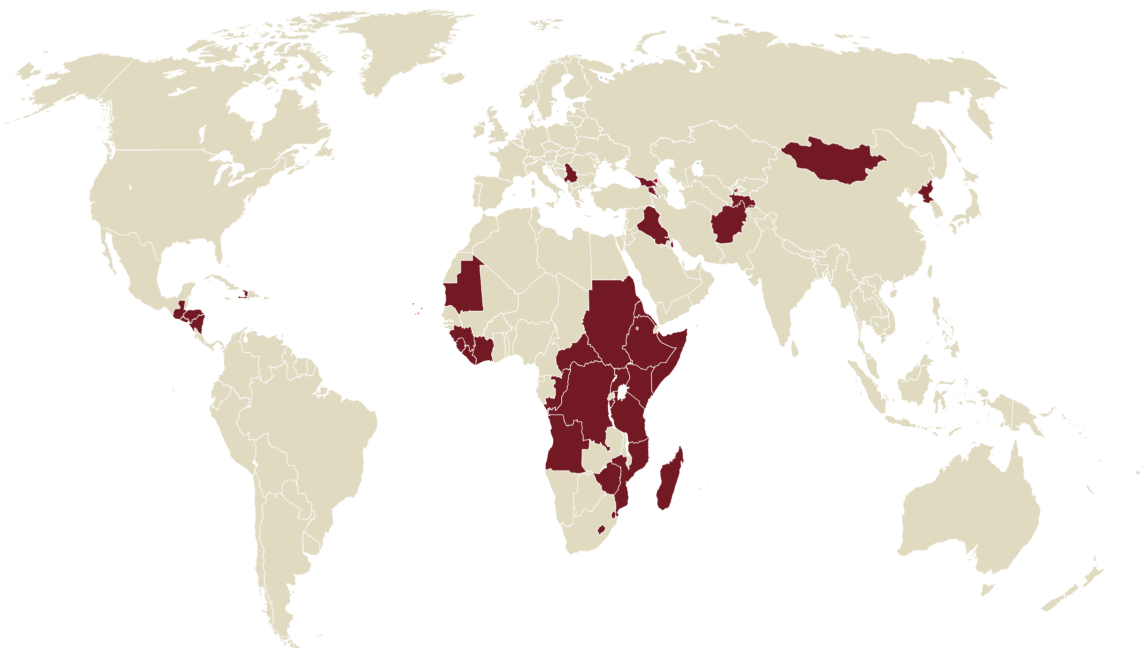
2. FOOD EMERGENCIES AND FOOD AID

- A large number of countries and people continue to be affected by food emergencies. As of August 2003, the number of countries facing serious food shortages requiring international assistance stood at 38 (Map 1). Twenty-three of these were in Africa, eight in Asia, five in Latin America and two in Europe. In many of these countries, the food shortages are compounded by the impact of the HIV-AIDS pandemic on food production, marketing, transport and utilization.

- Although adverse weather conditions are behind many of the emergency situations, human-produced disasters are also a major factor. Civil strife or the existence of internally displaced people or refugees are among the reasons for more than half of the reported food emergencies in Africa, as well as both instances in Europe. Conflict and economic problems were cited as the main cause of more than 35 percent of food emergencies between 1992 and 2003.

- The international price crisis that for three years has stricken the coffee sector has been a major cause of increased food insecurity in Central America, where four countries were reported as facing food emergencies.

MAP 1
Countries facing food emergencies



Source: FAO, GIEWS, October 2003.

TABLE 12
Per capita shipments of food aid in cereals
(In grain equivalent)

	(kg per capita)											
	90/91	91/92	92/93	93/94	94/95	95/96	96/97	97/98	98/99	99/00	00/01	01/02
Africa	10.0	8.6	10.2	5.0	5.0	3.4	2.3	2.7	3.0	3.4	4.3	2.6
Asia	1.0	1.0	0.9	1.1	1.2	1.2	0.7	0.9	1.5	1.2	1.2	1.1
Latin America and the Caribbean	4.4	4.3	3.4	3.4	2.4	1.2	1.2	1.0	1.9	1.5	1.2	1.4
Russian Federation			7.6	16.7	0.1	0.5	0.1	0.3	13.6	16.8	2.1	1.1
Other	1.1	1.6	3.1	1.5	0.7	0.4	0.4	0.2	0.4	0.6	0.3	0.3

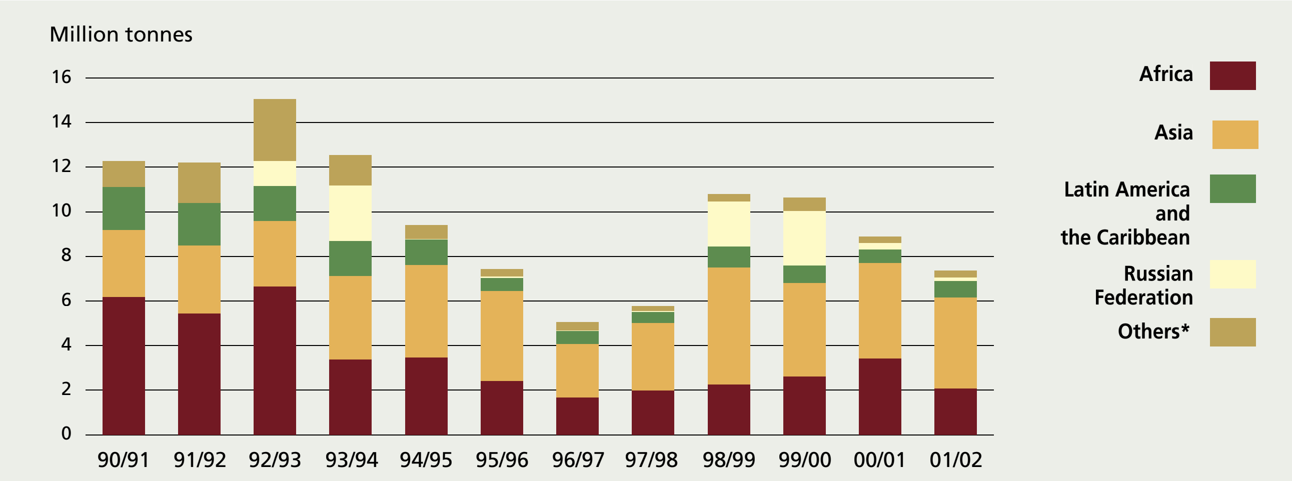
Note: years refer to the 12-month period July/June.
Source: WFP.

- Food aid in cereals fell to 7.4 million tonnes in 2001/02 (June to July), 2.3 million tonnes below that for 2000/01 and the lowest level since 1997/98. The decline concerned nearly all recipient regions. The top five recipients of cereal food aid in 2001/02 were Afghanistan, Bangladesh, the Democratic People's Republic of Korea, Ethiopia and the Philippines. The first three also topped the list in the previous year (Figures 18 and 19).

- Cereal food aid has been characterized by relatively large fluctuations but has declined overall relative to the level of the late 1980s and early 1990s. Larger overall shipments were recorded in 1998/99 and 1999/2000, largely as a result of major shipments to the Russian Federation.

- In per capita terms, shipments have declined substantially relative to the early 1990s (Table 12). Disregarding exceptionally large shipments to the Russian Federation in certain years, Africa remains the largest recipient in per capita terms, albeit at levels well below those of a decade ago.

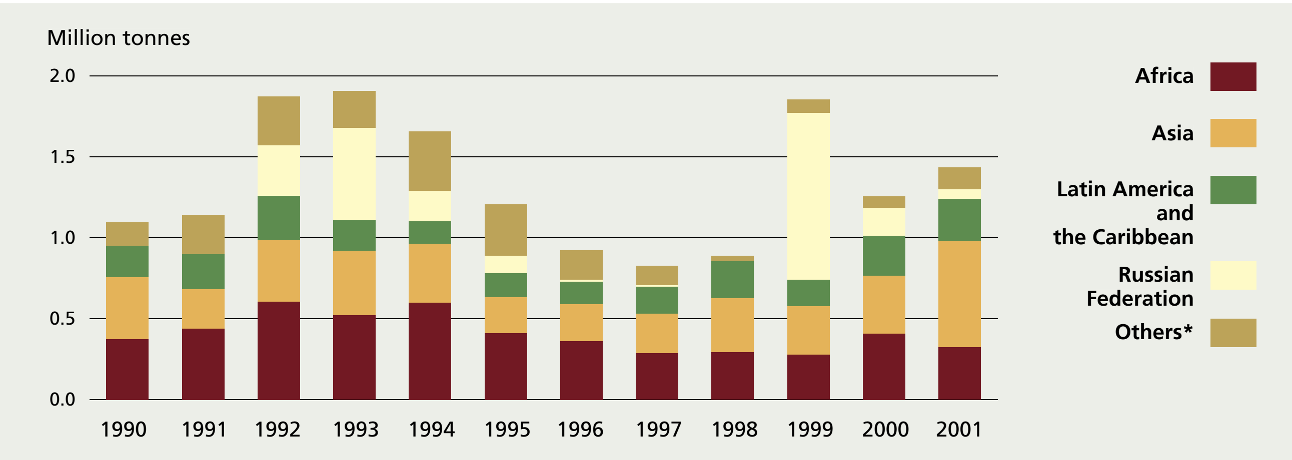
FIGURE 18
Recipients of food aid in cereals
(In grain equivalent)



* Including countries in transition
Note: years refer to the 12-month period July/June.

Source: WFP.

FIGURE 19
Recipients of food aid in non-cereals
(In grain equivalent)



* Including countries in transition

Source: WFP.

3. CROP AND LIVESTOCK PRODUCTION

- The rate of growth of global crop and livestock production has slowed in each of the last three years, following the strong output growth recorded in 1999 (Figure 20). The slow rate of growth in 2002 of less than 1 percent at the global level implies a reduction in output in per capita terms.

- Global output growth in each of the three years 2000–2002 is below the average of each of the three preceding decades. This pattern applies to both the developed and the developing country groups, both of which have seen output growth slow in each of the last three years. However, the trend towards lower agricultural output growth over the last few years, both in absolute and in per capita terms, is most clearly discernible for the developing country group (Figure 21).

- The trend towards lower agricultural output growth in the developing country group is essentially accounted for by Asia and the Pacific (more specifically, China), where the high rates of agricultural output growth recorded since the beginning of the economic reform process in the late 1970s have been tapering off in recent years. China has indeed attained very high levels of per capita food consumption, which is also expected to slow down growth in demand for food products in the future.

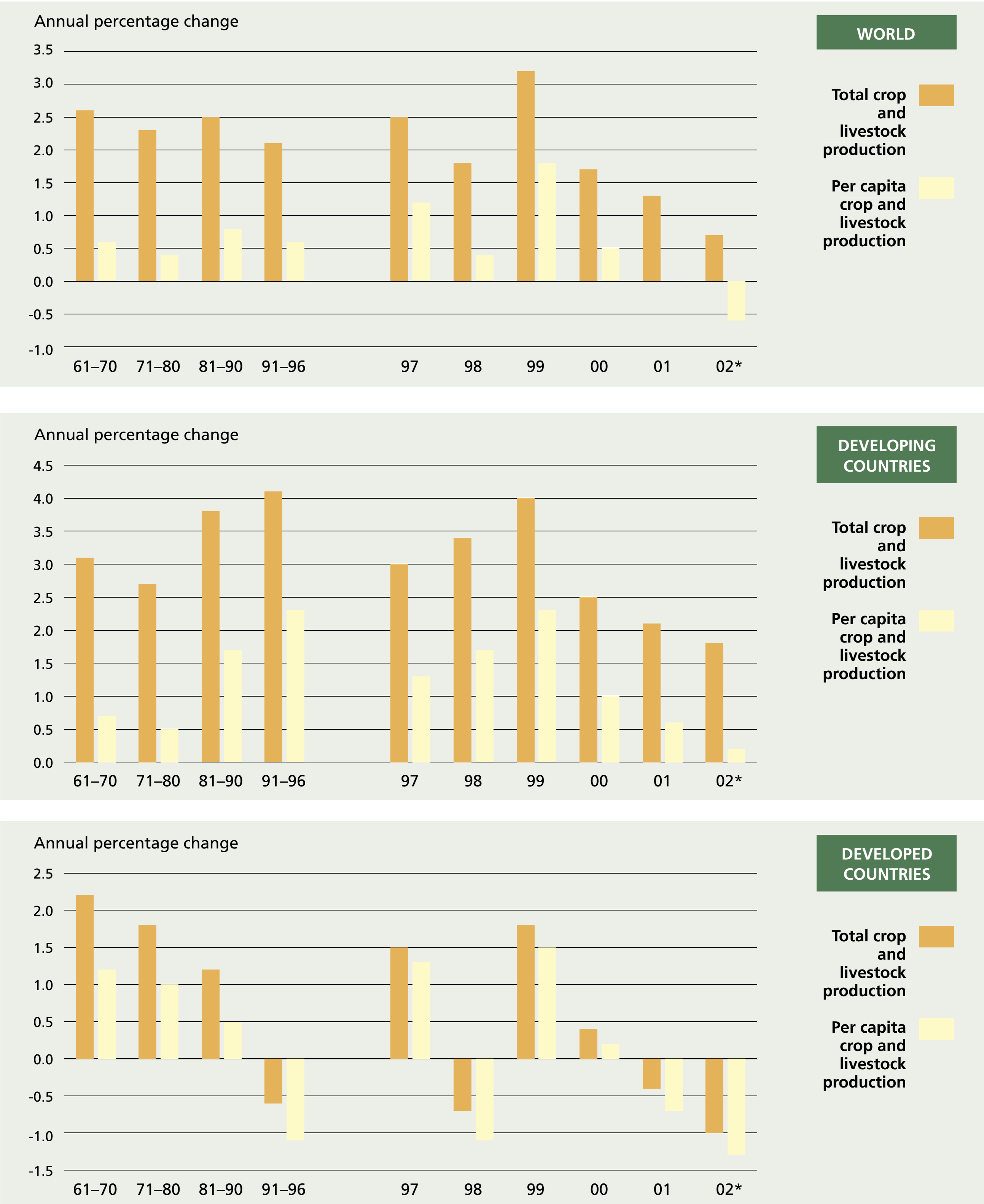
- Sub-Saharan Africa has recorded lower growth in agricultural output over the last three years. This follows relatively favourable rates of output growth during most of the 1990s. In 2002, the provisional data point to stagnant levels of production.

- Latin America and the Caribbean has experienced relatively favourable growth rates of production over the last five to six years, averaging around 3 percent per year, in line with the earlier part of the 1990s and above the lower rates of the 1980s.

- In the Near East and North Africa, agricultural performance continues to be characterized by pronounced fluctuations because of the climatic conditions of most countries in the region. After three years of consecutive declines in output for the region as a whole, provisional estimates suggest some recovery in levels of production in 2002.

- Long-term trends in per capita food production provide an indication of the contribution of the sector to food supplies in the regions (Figure 22). Over the last three decades, Latin America and the Caribbean and, in particular, Asia and the Pacific have seen sustained growth in per capita food production. In the Near East and North Africa, the increase has been far more limited amid pronounced fluctuations. Sub-Saharan Africa is the only region that has not seen increases in per capita food production over the last three decades; after a pronounced decline in the course of the 1970s and early 1980s, per capita food production has stagnated and is still at levels reported two decades ago.

FIGURE 20
Changes in crop and livestock production, total and per capita



* Preliminary

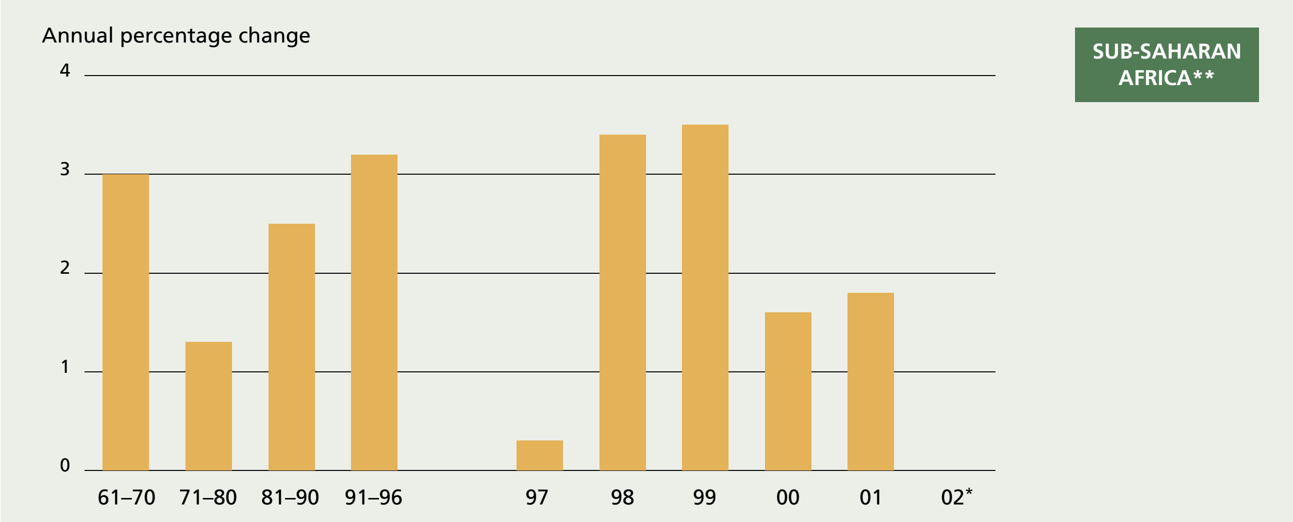
Source: FAO.

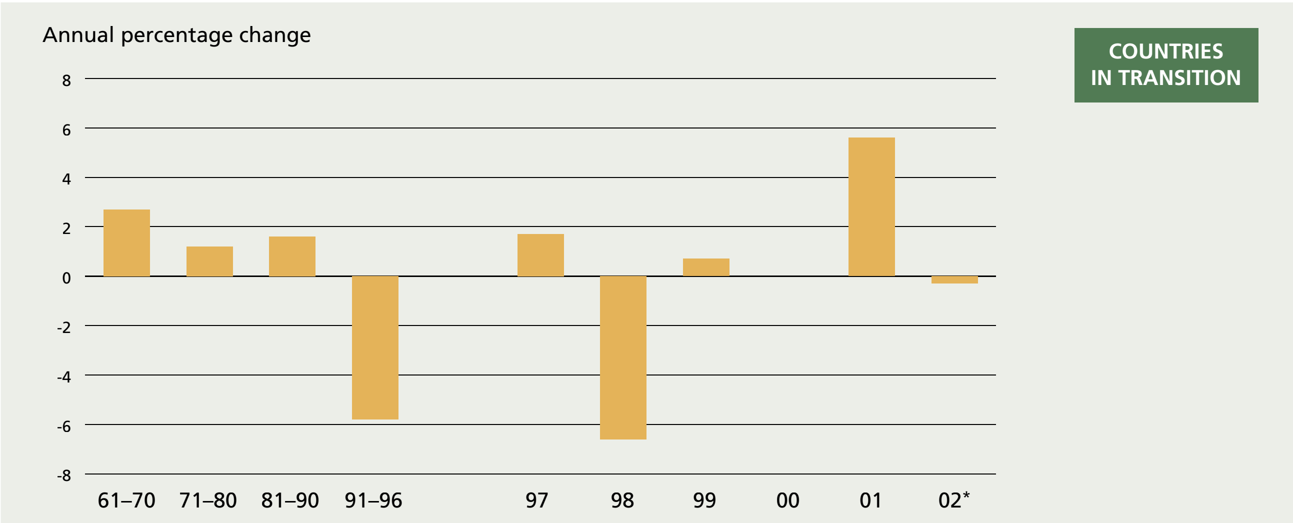
FIGURE 21
Changes in crop and livestock production, by region

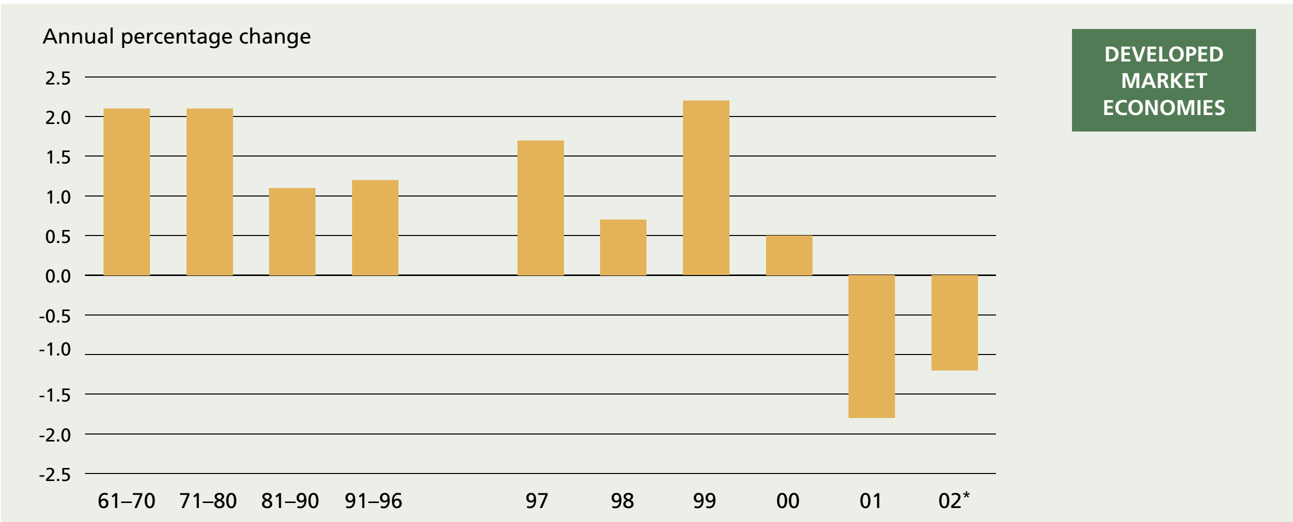
* Preliminary

(Cont.)

FIGURE 21 (cont.)
Changes in crop and livestock production, by region



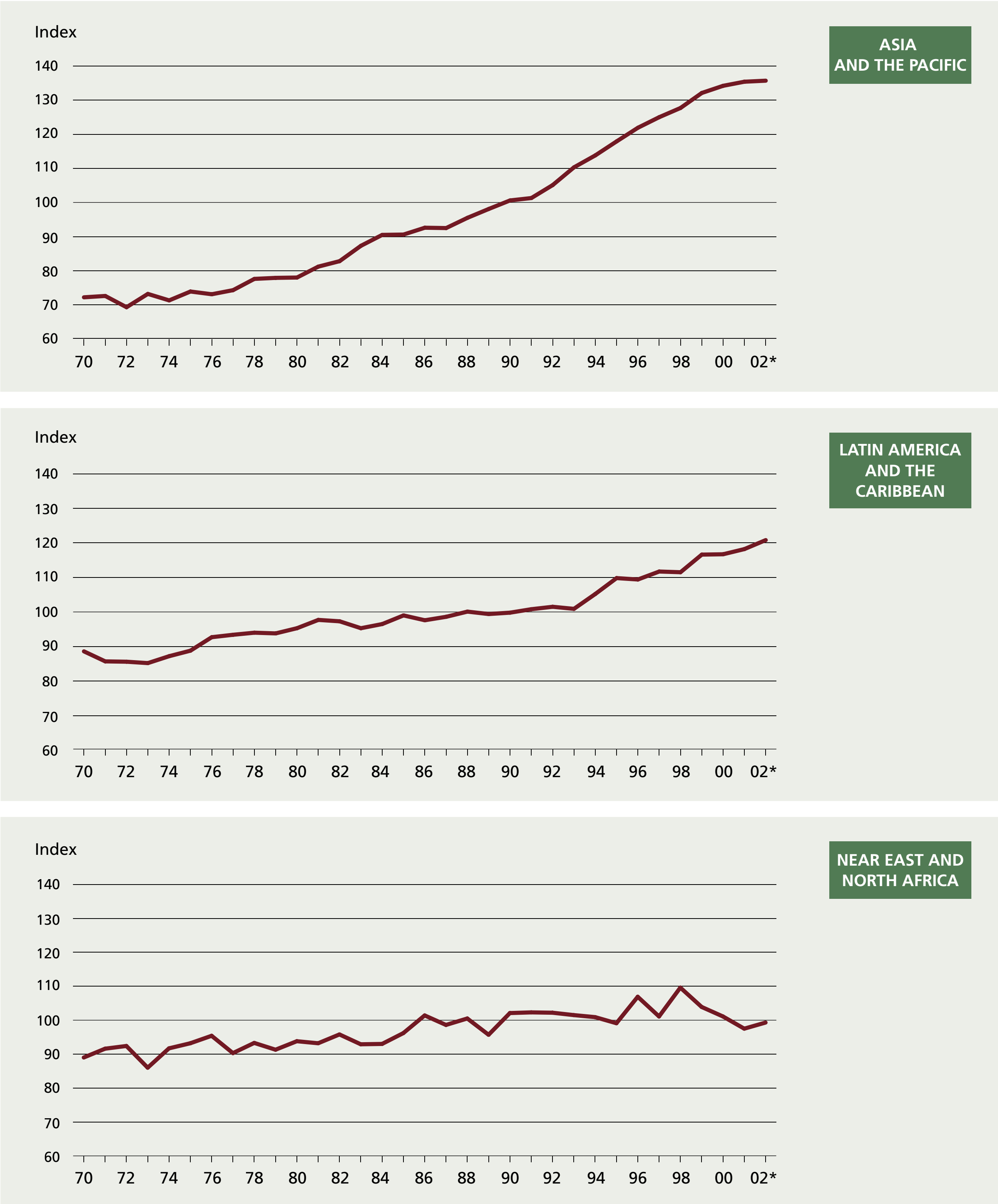




* Preliminary
** Including South Africa

Source: FAO.

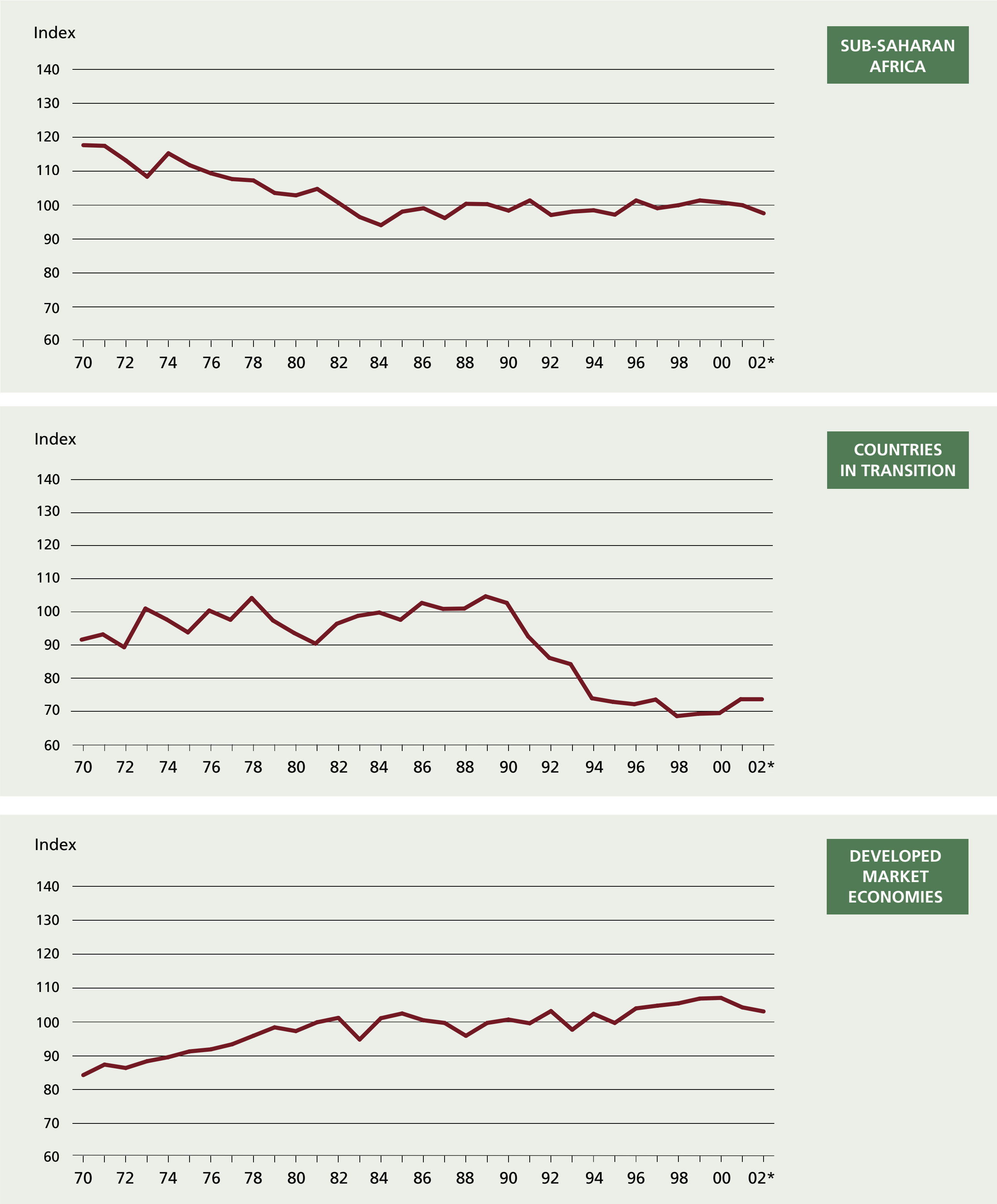
FIGURE 22
Long-term trend in per capita food production
(Index 1989–91 = 100)



*Preliminary

(Cont.)

FIGURE 22 (cont.)
Long-term trend in per capita food production
(Index 1989–91 = 100)



* Preliminary

Source: FAO.

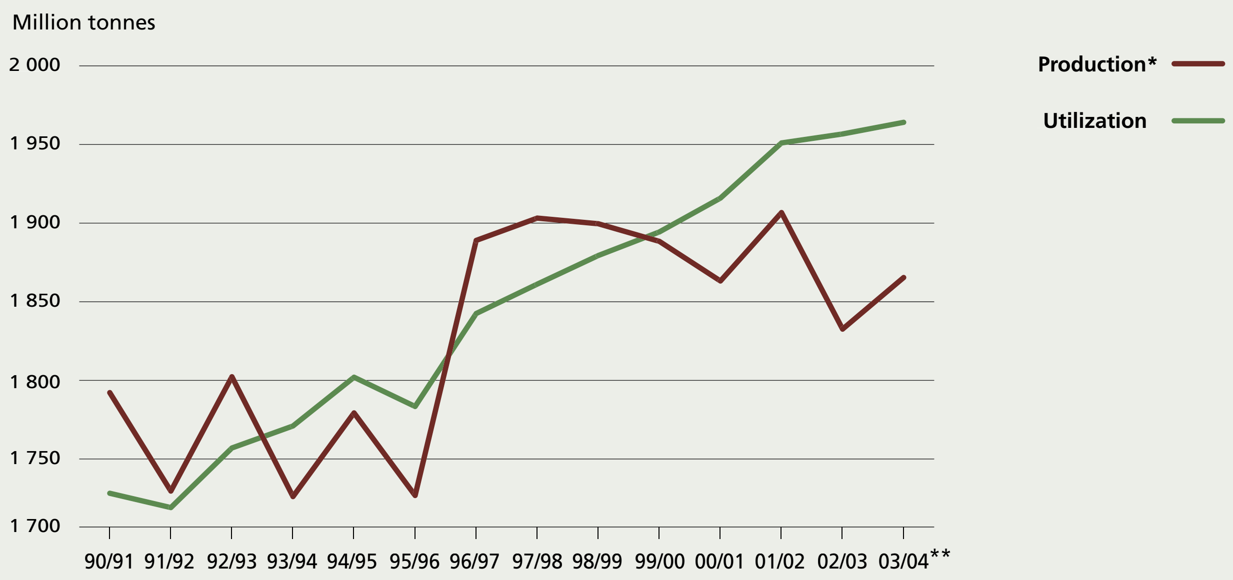
4. WORLD CEREAL SUPPLY SITUATION

- Since the strong increase in 1996, global cereal production has been stagnating. Global utilization, on the other hand, has been continuing on an upward trend and has been exceeding production by significant amounts since the 2000/01 marketing year (Figures 23 and 24).

- FAO's latest forecasts for global cereal production in 2003 and the first forecast for utilization in 2003/04 indicate that output will remain below the expected level of utilization and stocks will have to be drawn down again in 2004 for the fourth consecutive year.

- As in the previous seasons, lower stocks in China account for the bulk of the reduction in world stocks. Of the overall decline in cereal stocks since 1999, China alone accounted for nearly 70 percent as a result of deliberate policies to downsize cereal inventories through exports.

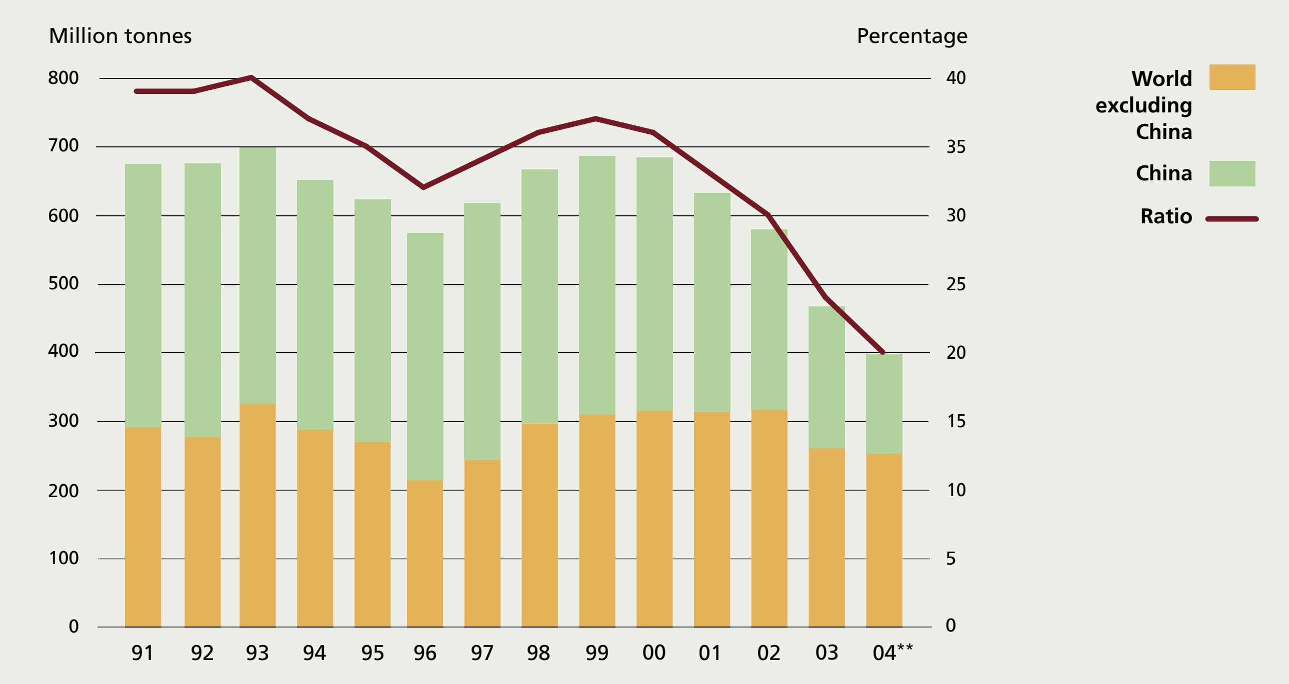
FIGURE 23
World cereal production and utilization



* Data refer to the calendar year of the first year shown
** Forecast

Source: FAO.

FIGURE 24
World cereal stocks and stocks-to-utilization ratio*



* Stock data are based on aggregate carryovers at the end of national crop years and do not represent world stock levels at any point in time
** Forecast

Source: FAO.

5. INTERNATIONAL COMMODITY PRICE TRENDS

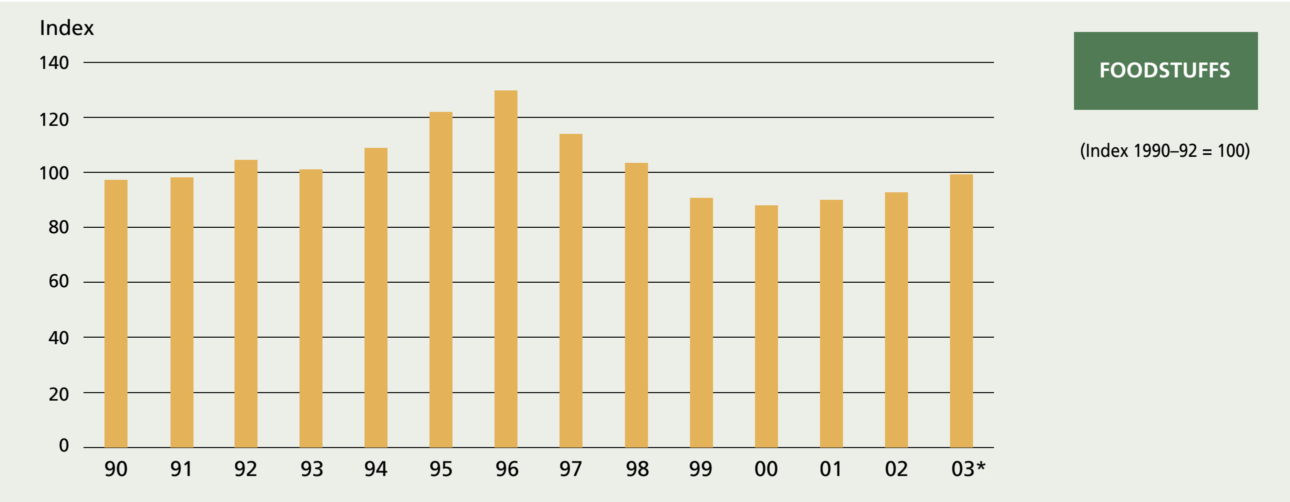
- Overall, agricultural commodity prices peaked in the mid-1990s, and then tended downwards during the second half of the decade, although for some commodities prices began to recover during 2001 and 2002 (Figure 25).

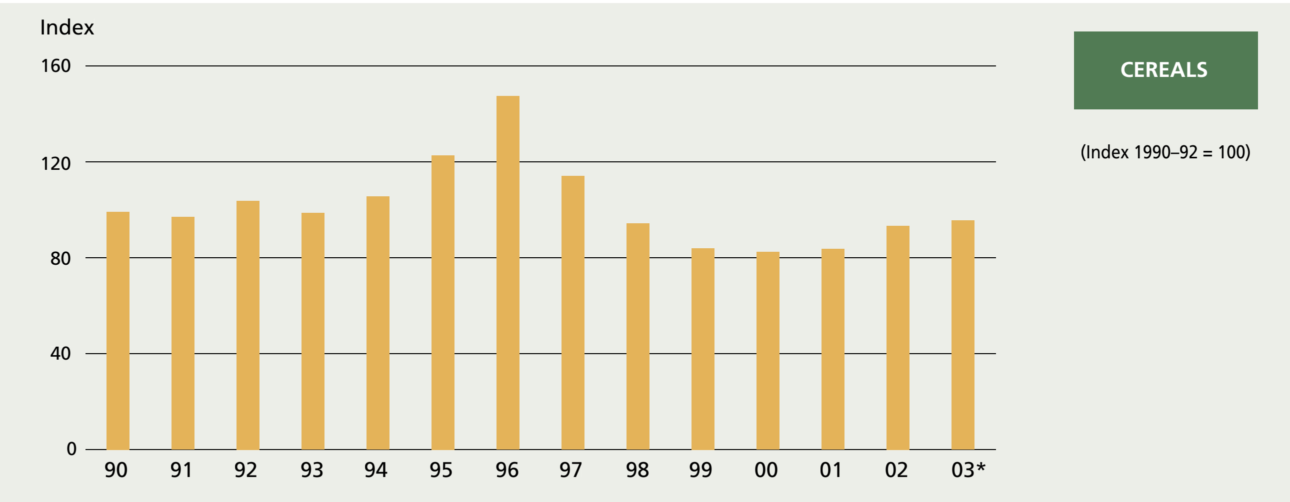
- In general, agricultural commodity prices during the second half of the 1990s were influenced mainly by supply response to previously high prices and prices of close substitutes, the Asian financial crisis (which undermined economic growth prospects and lowered demand in many countries) and the continuing support to production and exports by a number of countries.

- The sharpest price decline has been that of coffee. Significant oversupply on world markets, mainly as a result of the expansion of planted area in Viet Nam and the devaluation of the Brazilian real, led to further sharp price declines in 2001, bringing average prices for the year to around one-third of the level in 1997. This prolonged period of low prices resulted in supply reductions that have since contributed to some recovery in prices, although these nevertheless remain depressed.

- Lower international prices have moderated the food import bills of developing countries, which, as a group, are now net food importers. However, although lower basic food prices on international markets bring short-term benefits to net food-importing developing countries, lower international prices can also have negative impacts on domestic production in developing countries that might have lingering effects on their food security.
- Although many countries may have benefited from lower prices, others have experienced negative effects on their ability to generate export earnings, in particular developing country exporters of agricultural raw materials, beverages and other tropical products, many of which are often dependent for a significant share of their export earnings on one or just a few agricultural exports.

FIGURE 25
Commodity price trends

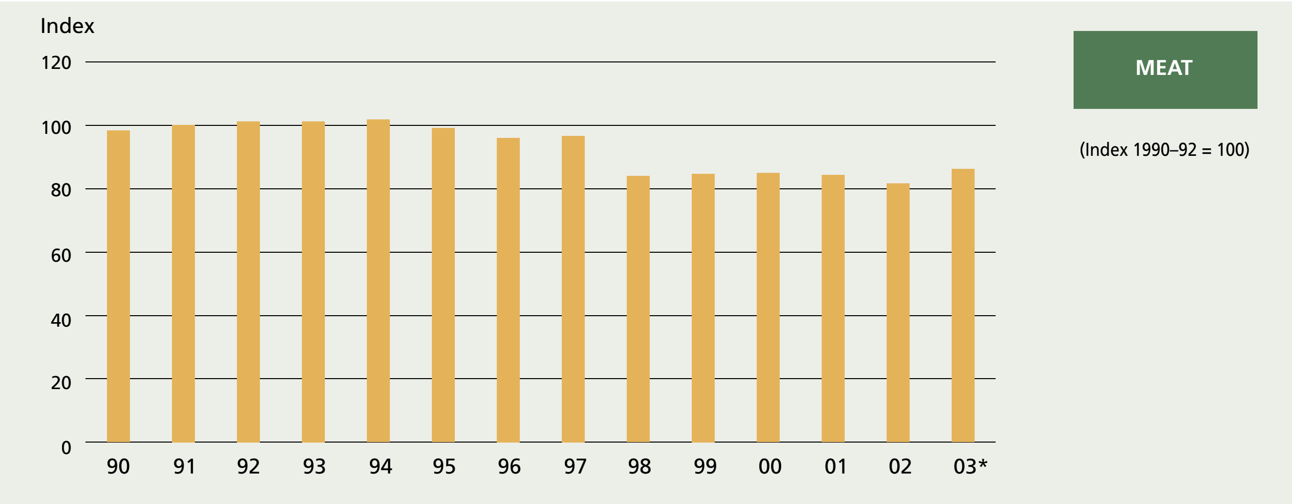


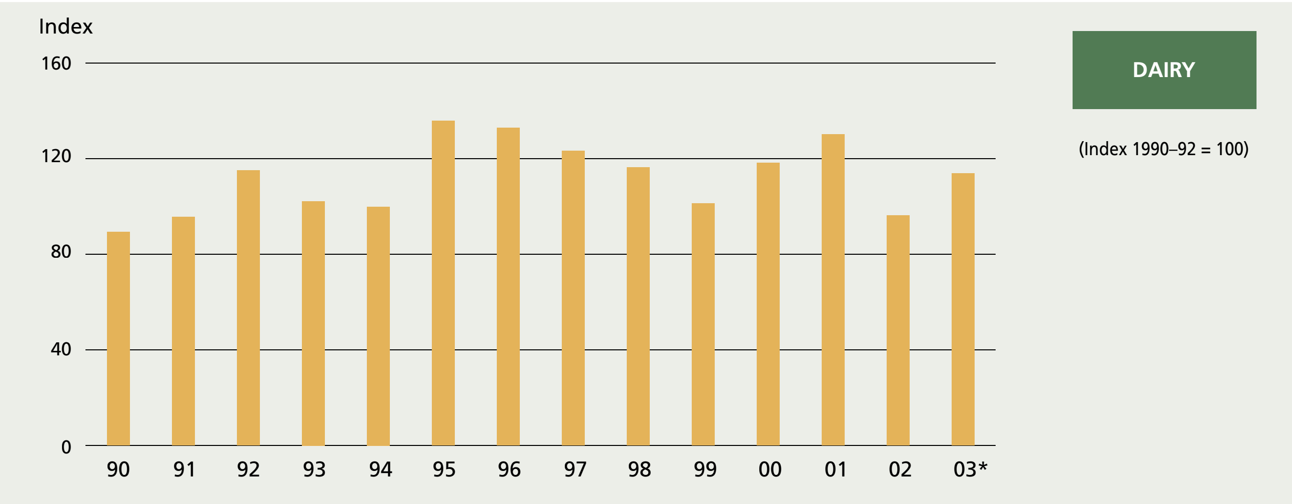


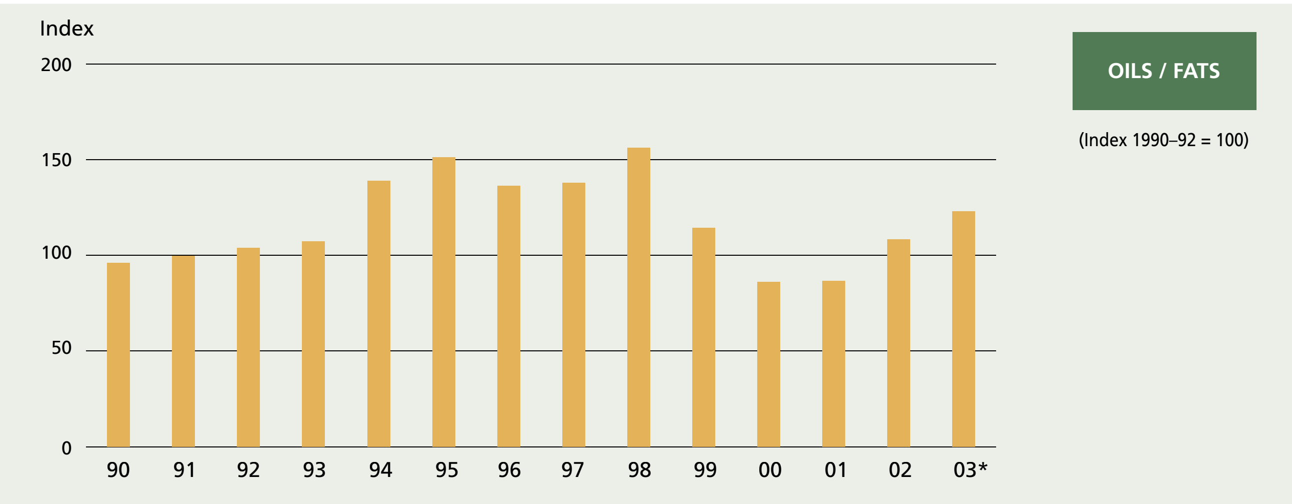
* Eight-month average, January–August

(Cont.)

FIGURE 25 (cont.)
Commodity price trends



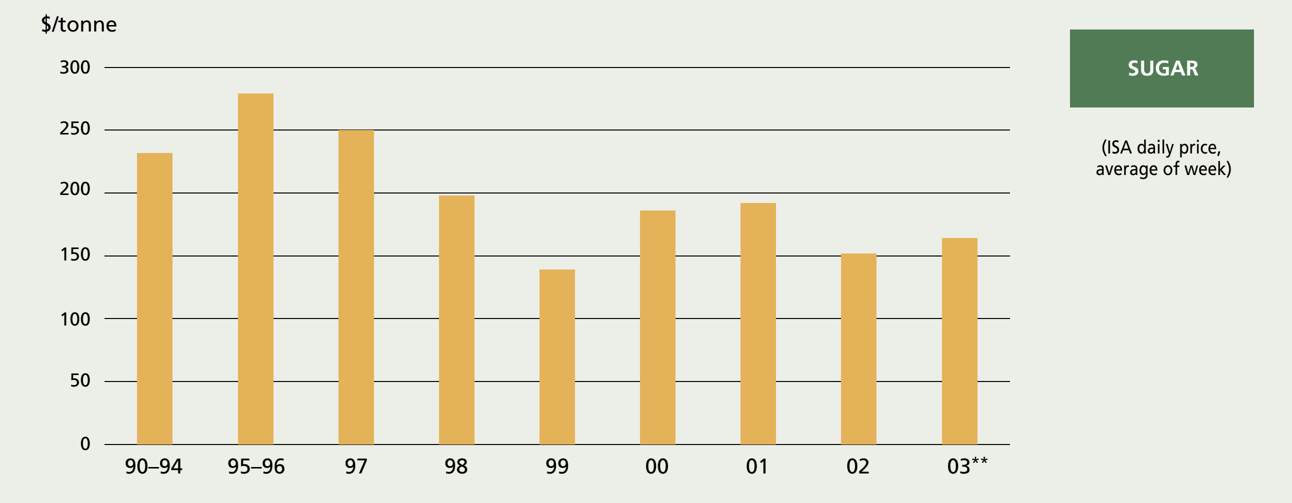


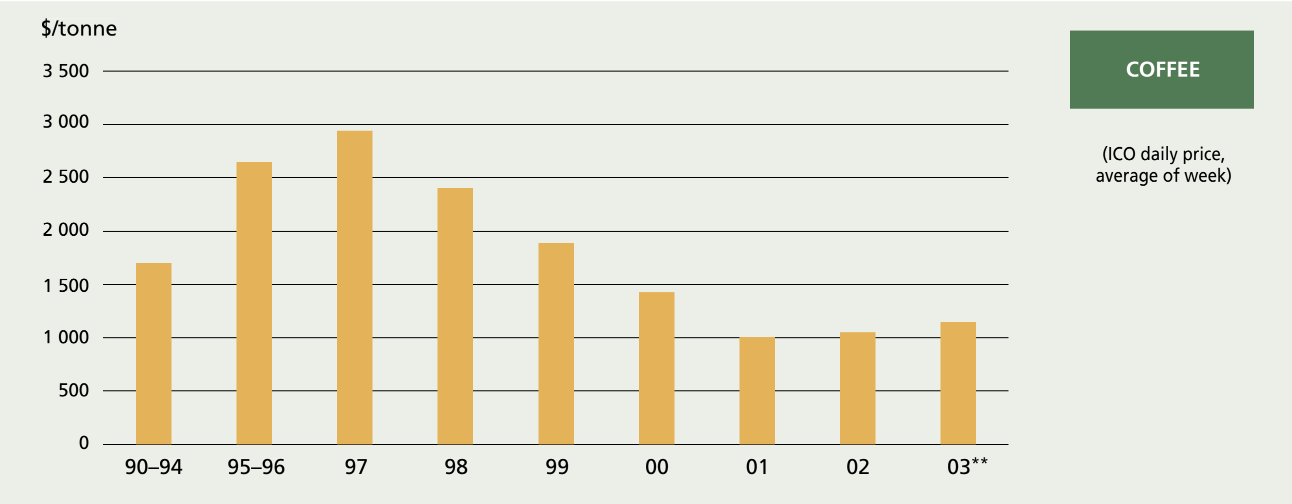


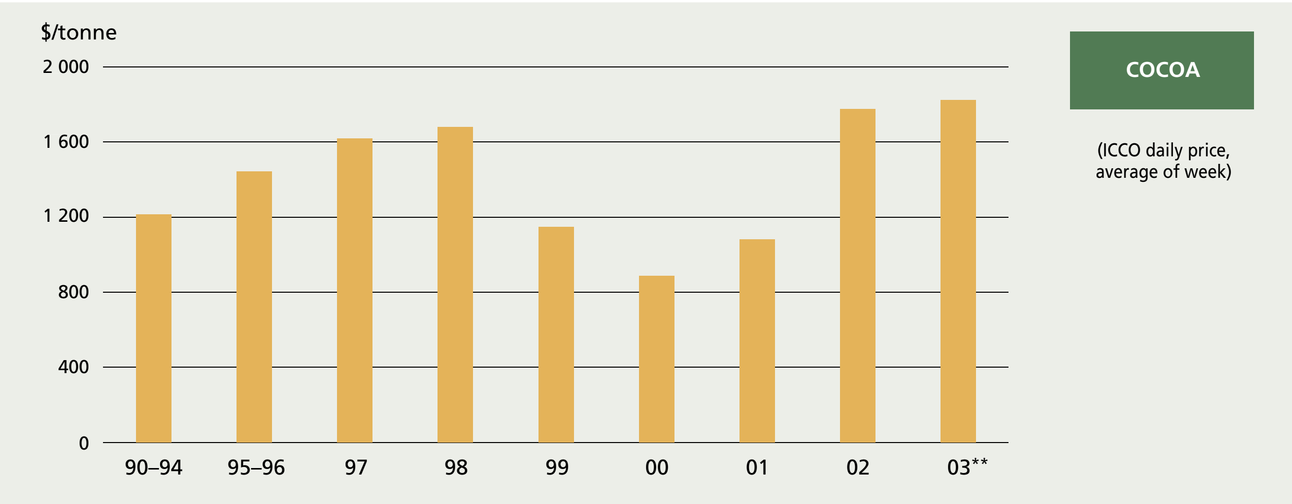
* Eight-month average, January–August

(Cont.)

FIGURE 25 (cont.)
Commodity price trends



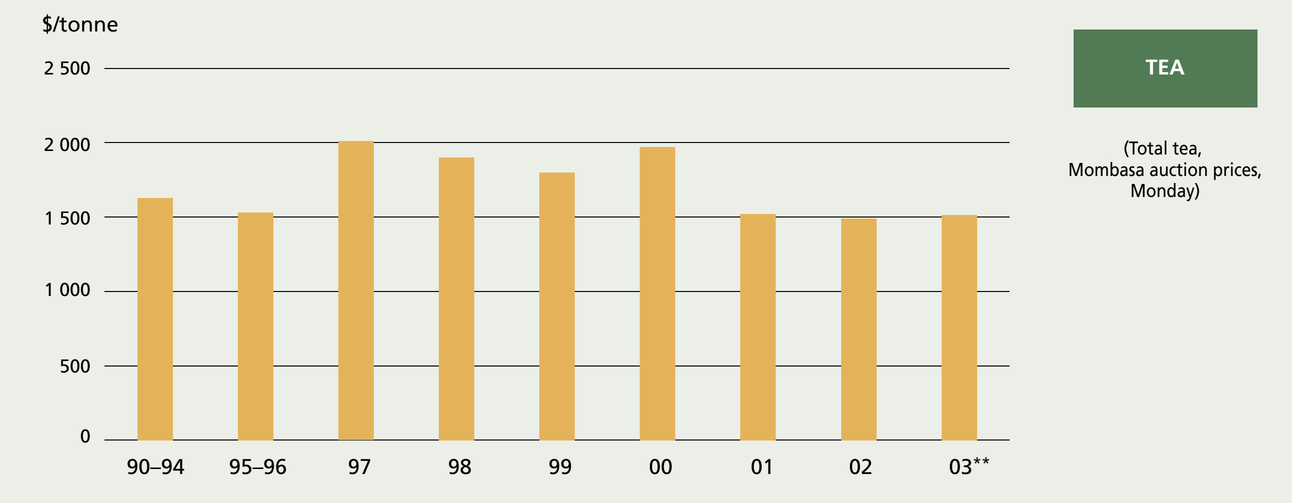


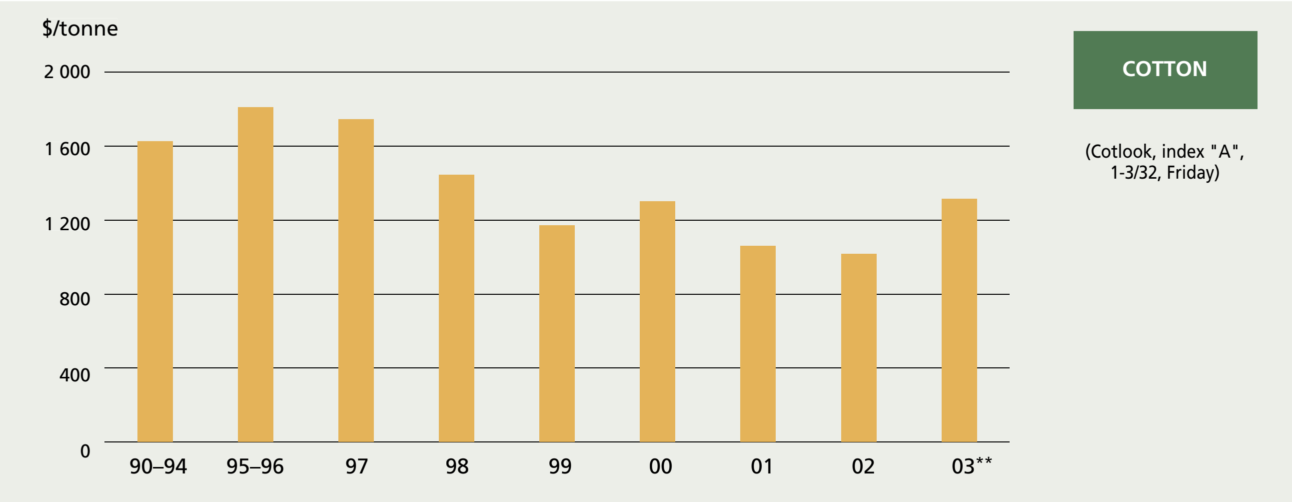


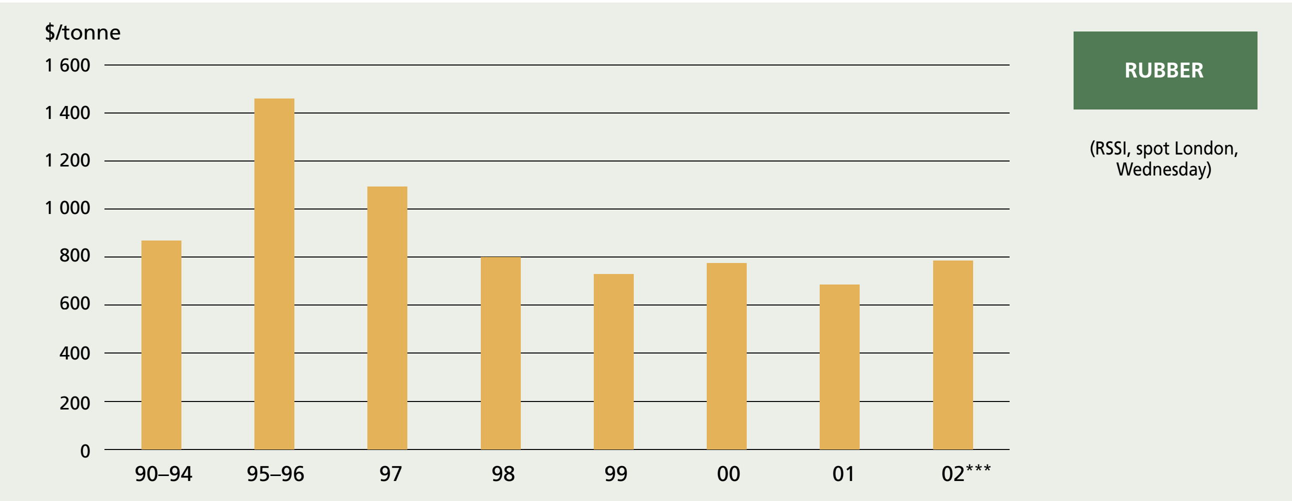
** Nine-month average, January–September

(Cont.)

FIGURE 25 (cont.)
Commodity price trends







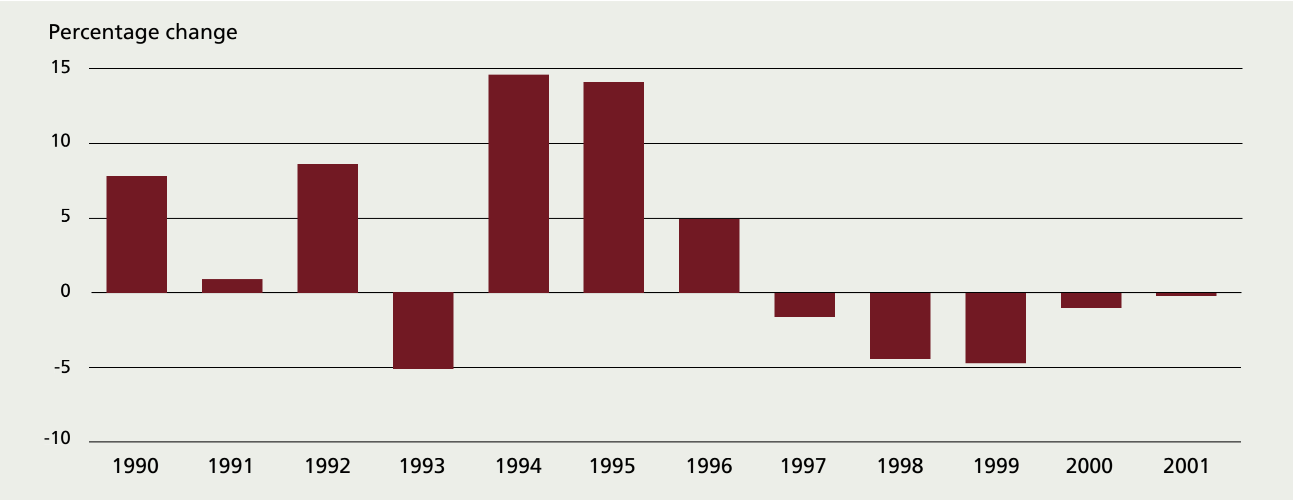
** Nine-month average, January–September
*** Six-month average, January–June

Source: FAO.

6. AGRICULTURAL TRADE

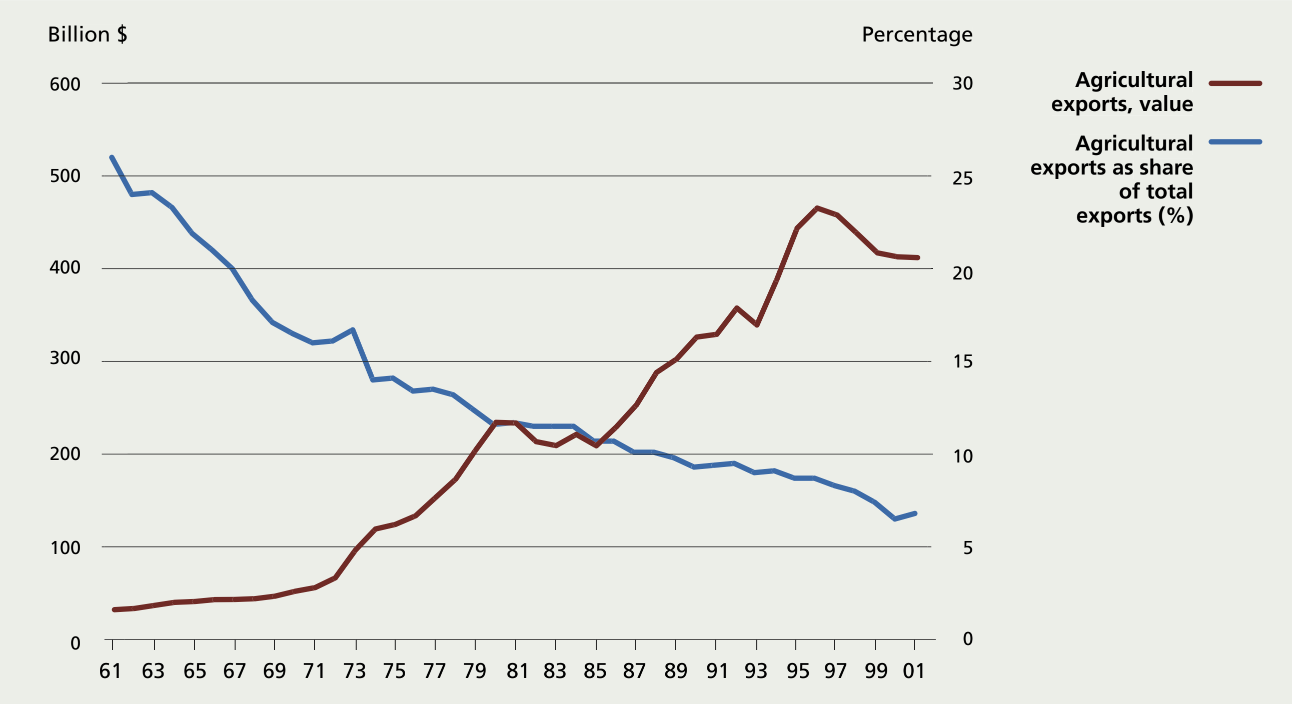
- After a relatively strong expansion in the mid-1990s, global agricultural exports have been declining in value terms between 1997 and 2001 (Figure 26), leading to a further reduction in the share of agricultural trade to less than 7 percent of total merchandise trade – in continuation of the long-term trend in this direction (Figure 27).
- The agricultural trade of both developed and developing countries has been affected by the decline in value terms (Figures 28 and 29).
- Agricultural imports and exports of developing countries have been roughly in balance over the last decade but with widely varying situations among the developing country regions.
- In particular, Latin America and the Caribbean has seen a widening of its agricultural trade surplus. At the same time, Asia and the Pacific has become a net agricultural importer, and the significant structural deficit of the Near East and North Africa has shown no signs of diminishing.

FIGURE 26
Annual change in value of global agricultural exports
(In US dollar terms)



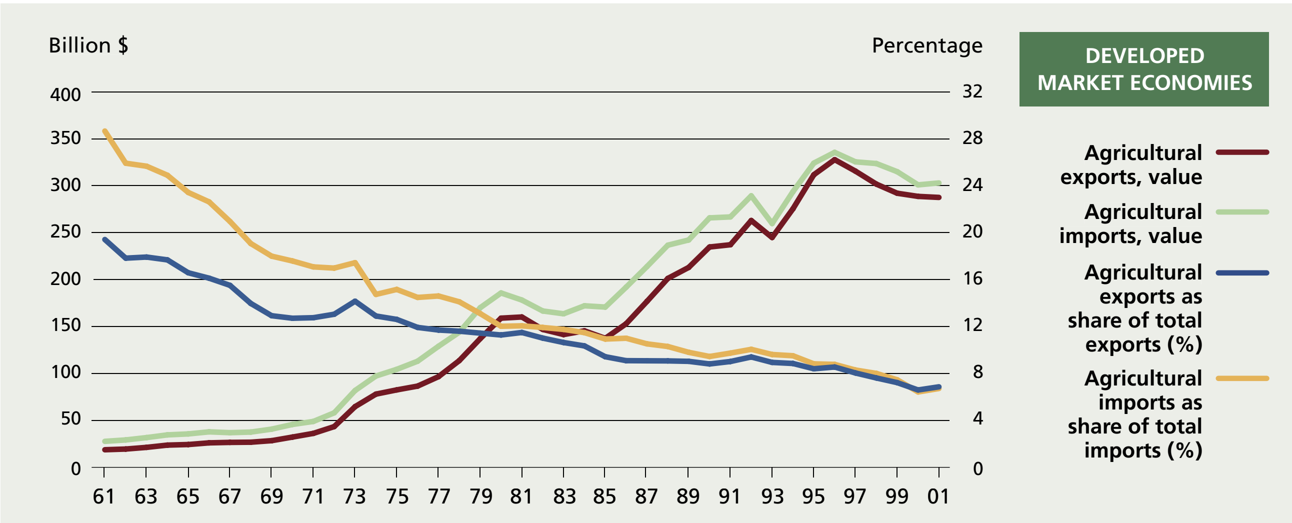
Source: FAO.

FIGURE 27
Global agricultural exports



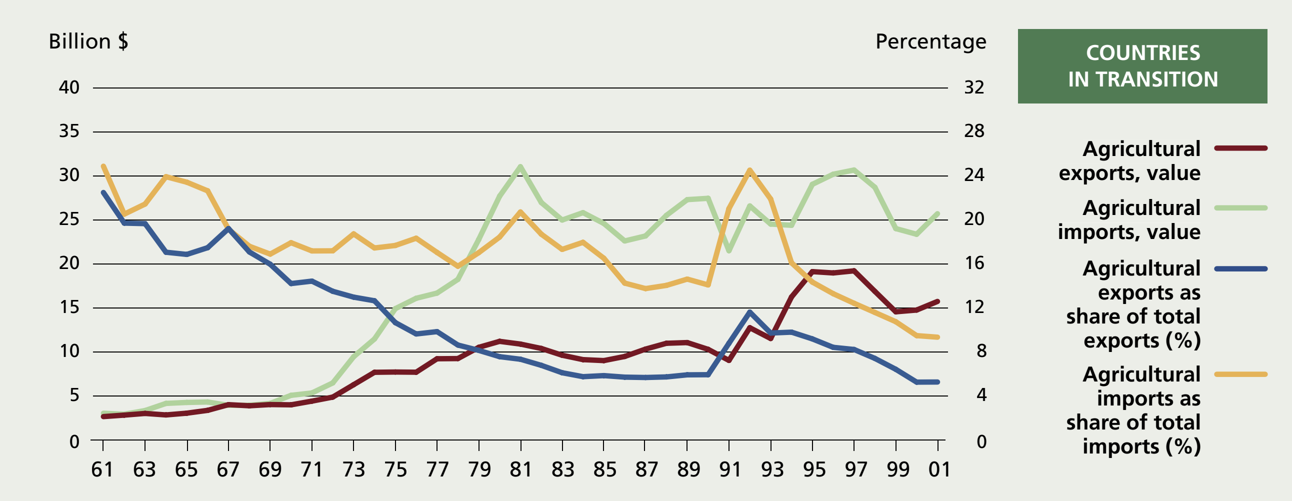
Source: FAO.

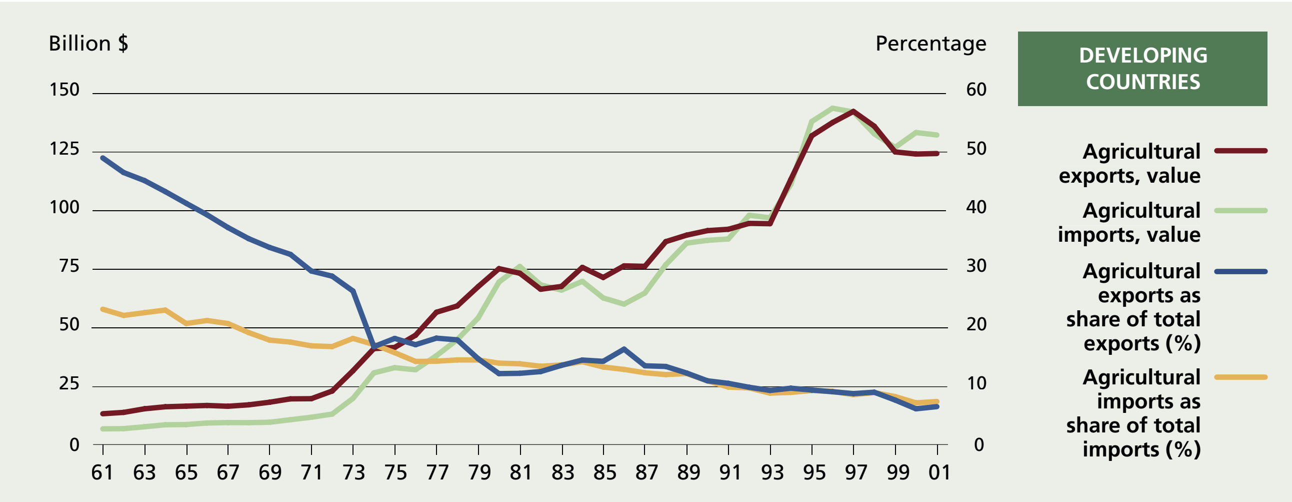
FIGURE 28
Agricultural imports and exports, by region

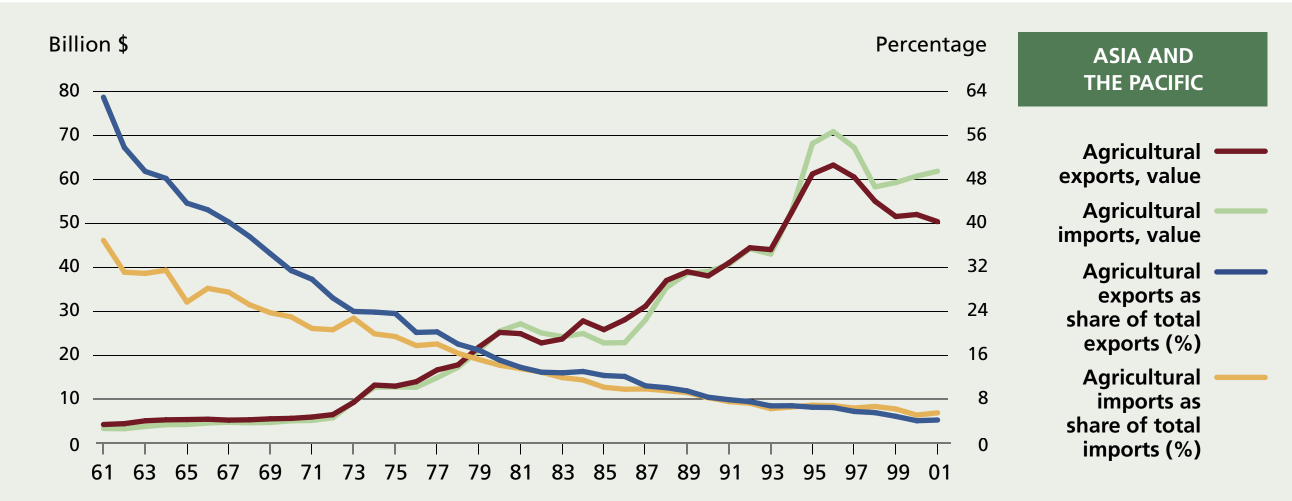


(Cont.)

FIGURE 28 (cont.)
Agricultural imports and exports, by region

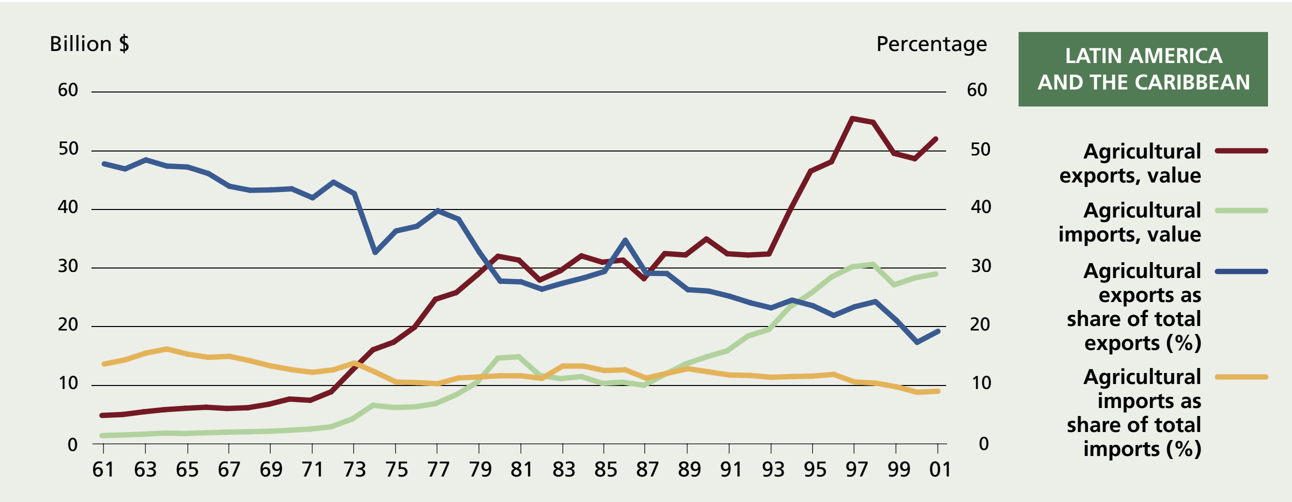


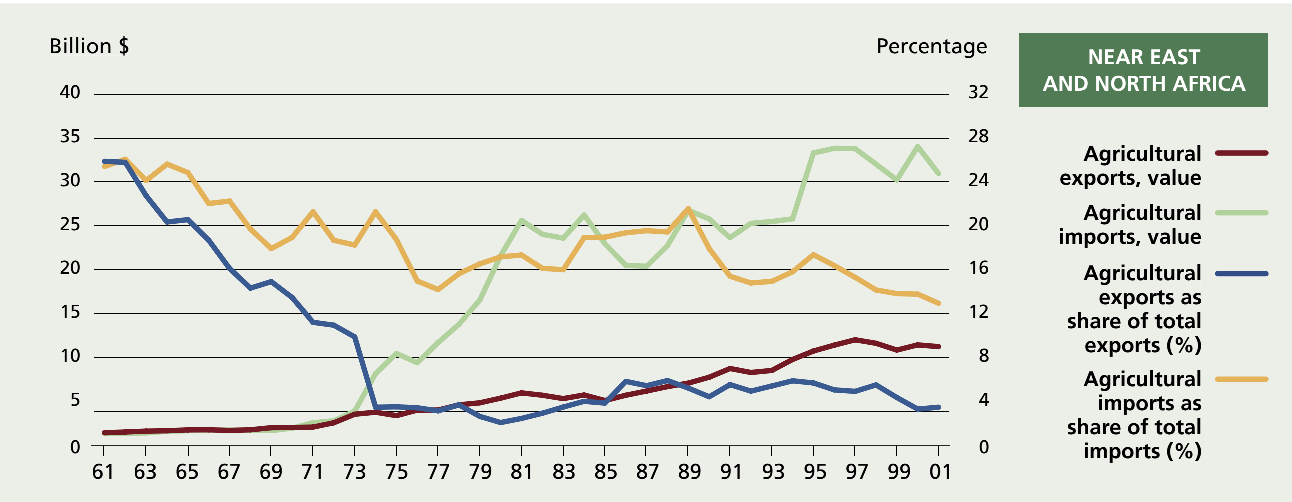


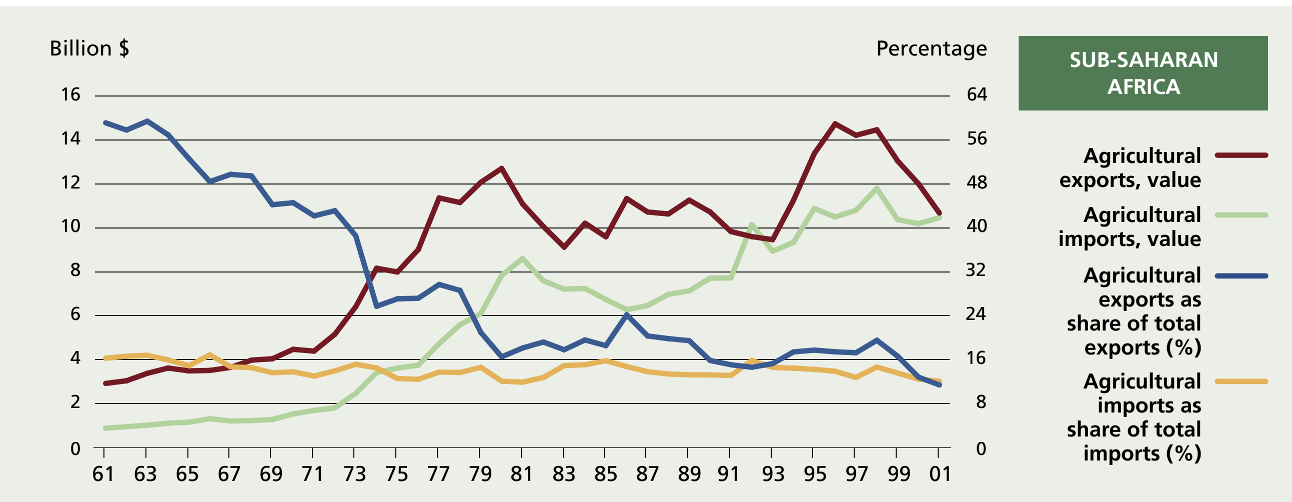


(Cont.)

FIGURE 28 (cont.)
Agricultural imports and exports, by region

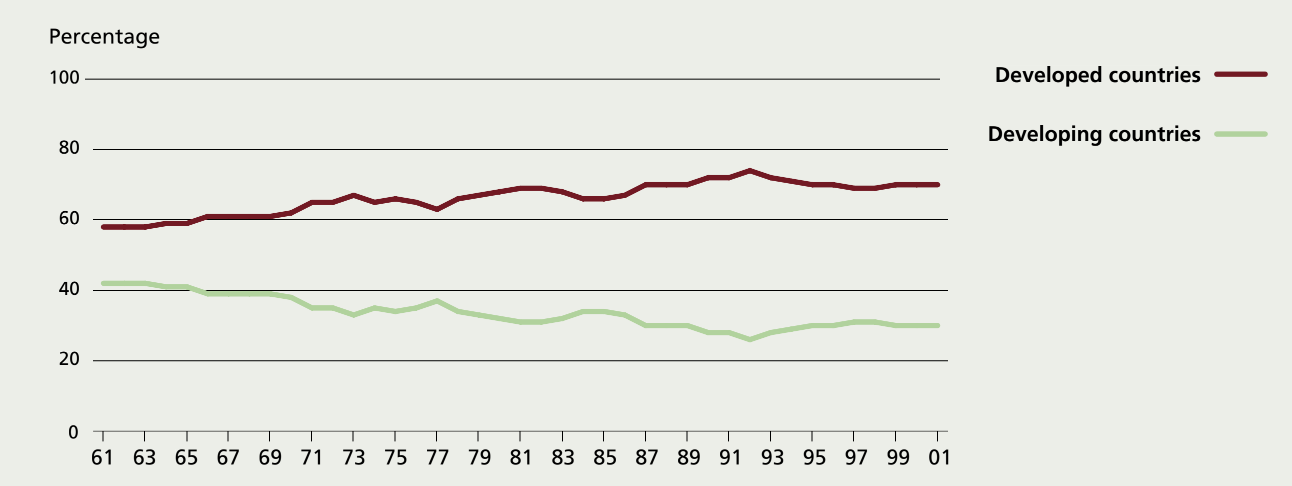


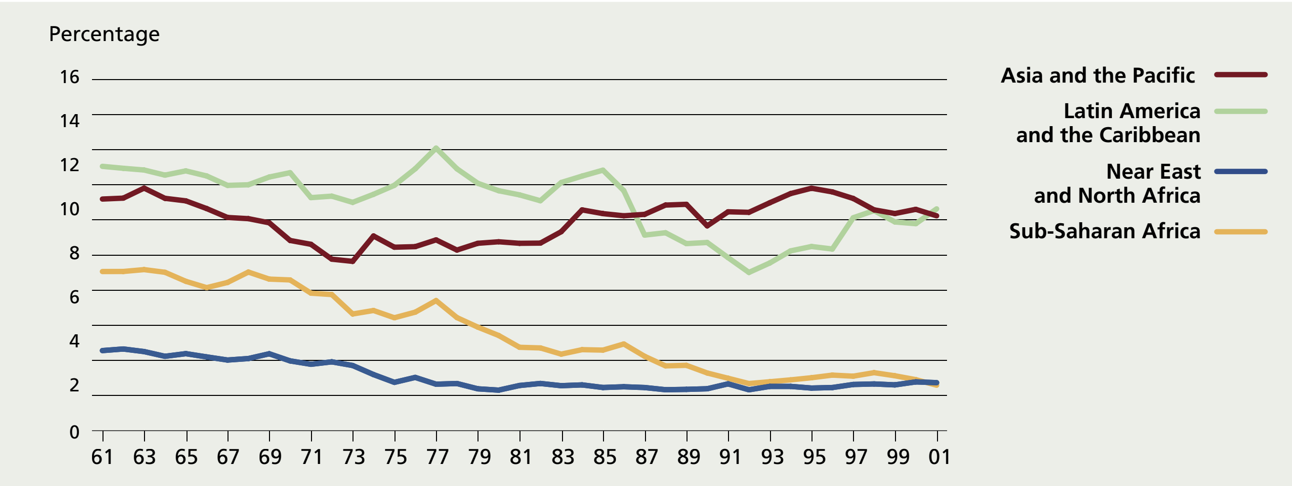




Source: FAO.

FIGURE 29
Share of world agricultural exports, by region





Source: FAO.

7. EXTERNAL ASSISTANCE TO AGRICULTURE

- Measured at constant 1995 prices, external assistance to agriculture declined in 1999 following increases in the three preceding years (Figures 30 and 31). Data for 2000 indicate stagnant levels of external assistance to agriculture.

- Most of the decline in 1999 was a result of lower levels of multilateral assistance. Overall, multilateral assistance has been fluctuating more over the last few years, whereas bilateral assistance has remained relatively more constant.

- In real terms, external assistance to agriculture has fallen significantly since the early 1980s.

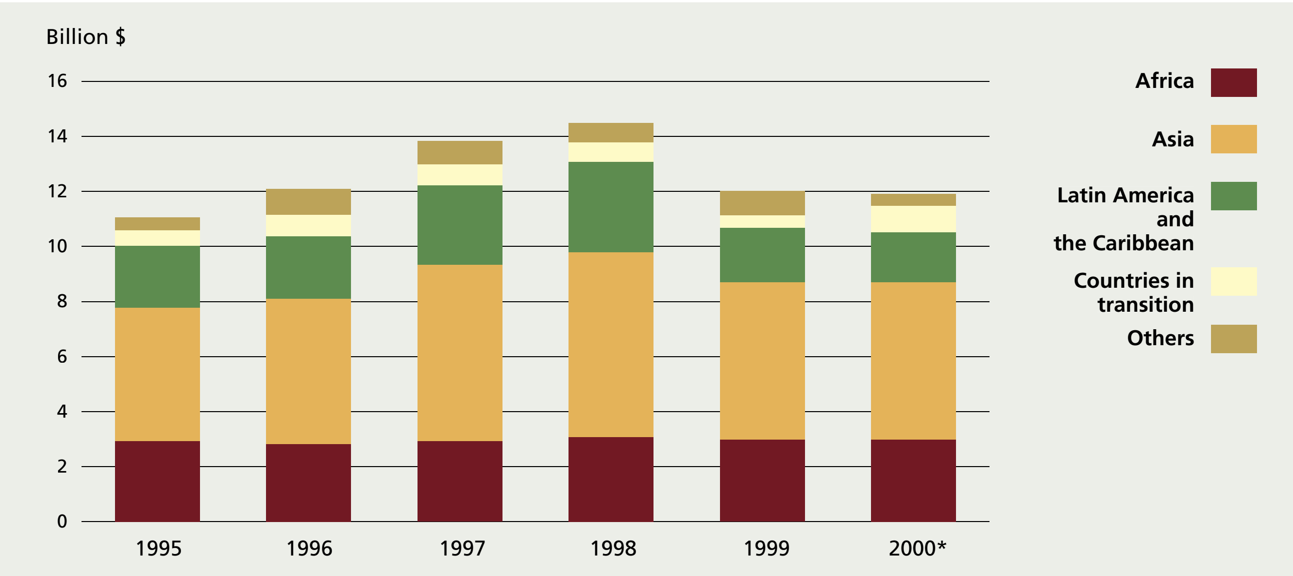
- On the other hand, the share of concessional assistance in the total has tended to increase, reaching more than 80 percent in 2000 (Figure 32).

- When measured per agricultural worker, external assistance to agriculture has declined significantly since the peak in the early 1980s. The decline has been particularly severe in sub-Saharan Africa, where external assistance per employed person in agriculture is roughly one-quarter of the peak 1982 level.

- There are significant differences in assistance per agricultural worker among the developing country regions, with levels in Latin America and the Caribbean vastly exceeding those of the other regions (Figure 33).

- External assistance to agriculture also does not tend to reach the neediest countries in terms of the prevalence of undernourishment. Indeed, external assistance per agricultural worker is higher in those countries with the lowest prevalence of undernourished people in the population (Figure 34).

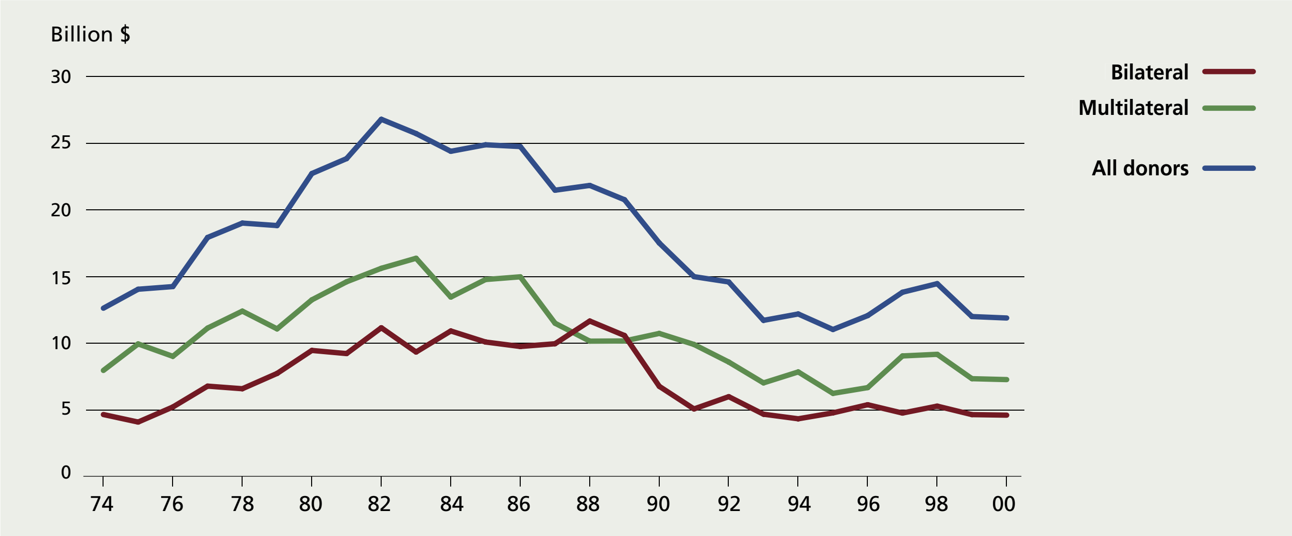
FIGURE 30
Commitments of external assistance to agriculture, by main recipient regions
(At constant 1995 prices)



* Incomplete and provisional data

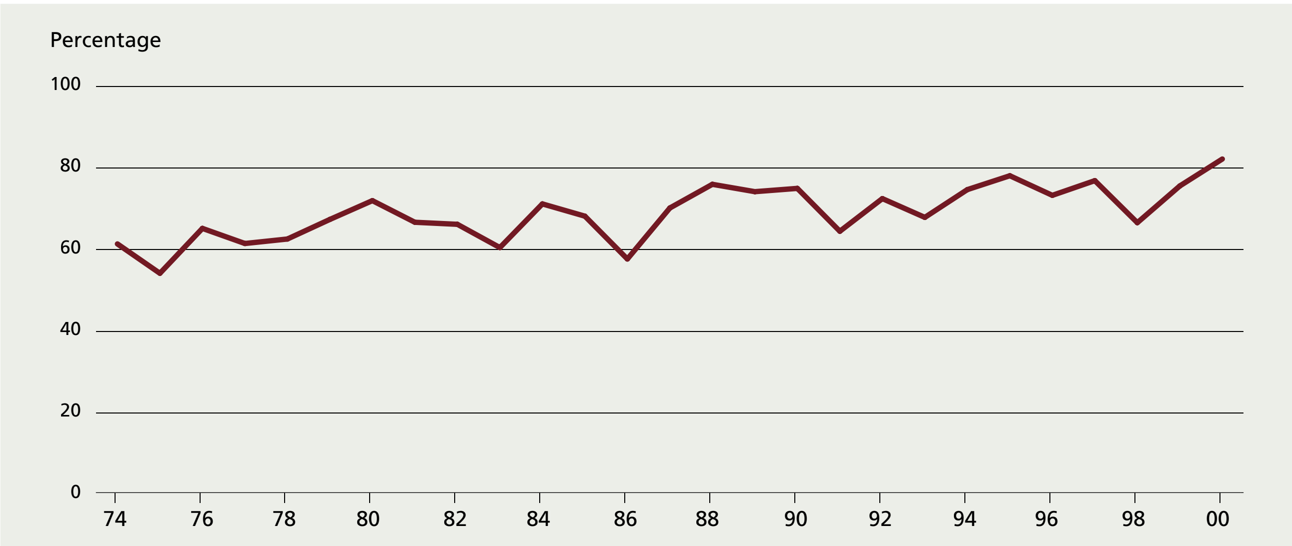
Source: FAO.

FIGURE 31
Long-term trend in external assistance to agriculture, 1974–2000
(At constant 1995 prices)



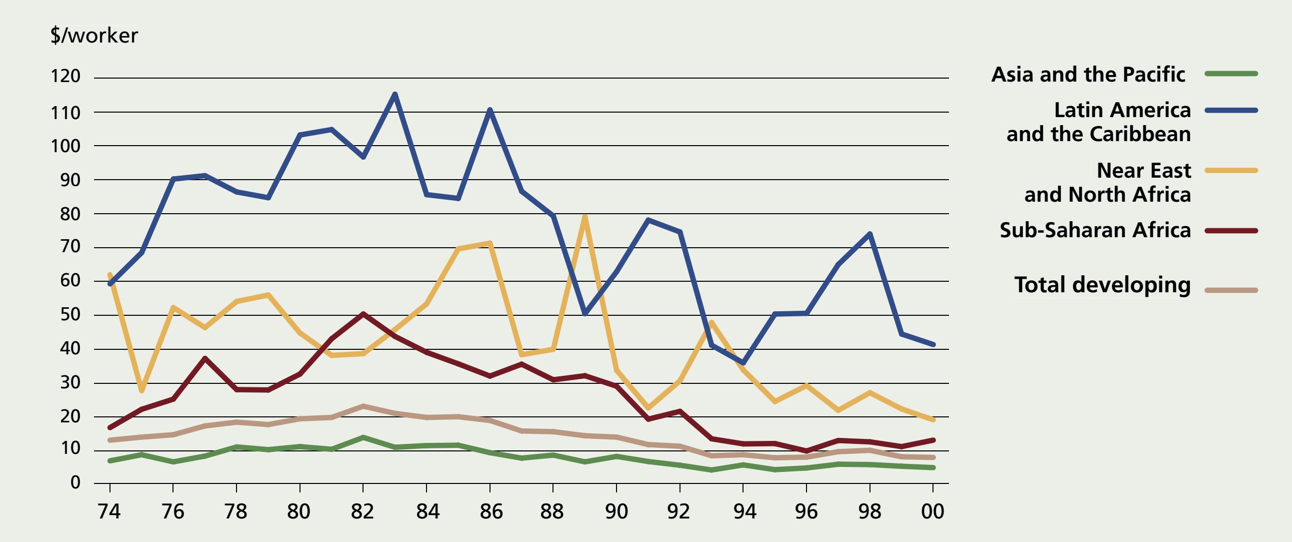
Source: FAO.

FIGURE 32
Share of concessional assistance in total assistance to agriculture



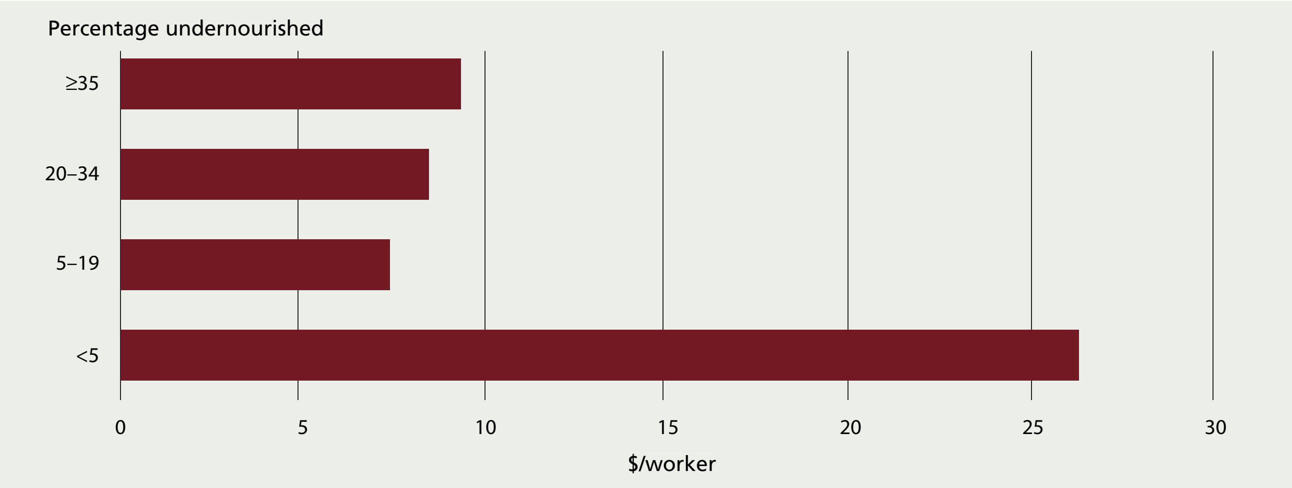
Source: FAO.

FIGURE 33
External assistance to agriculture per agricultural worker
(At constant 1995 prices)



Source: FAO.

FIGURE 34
External assistance to agriculture per agricultural worker according to prevalence of undernourishment, 1998–2000
(At constant 1995 prices)

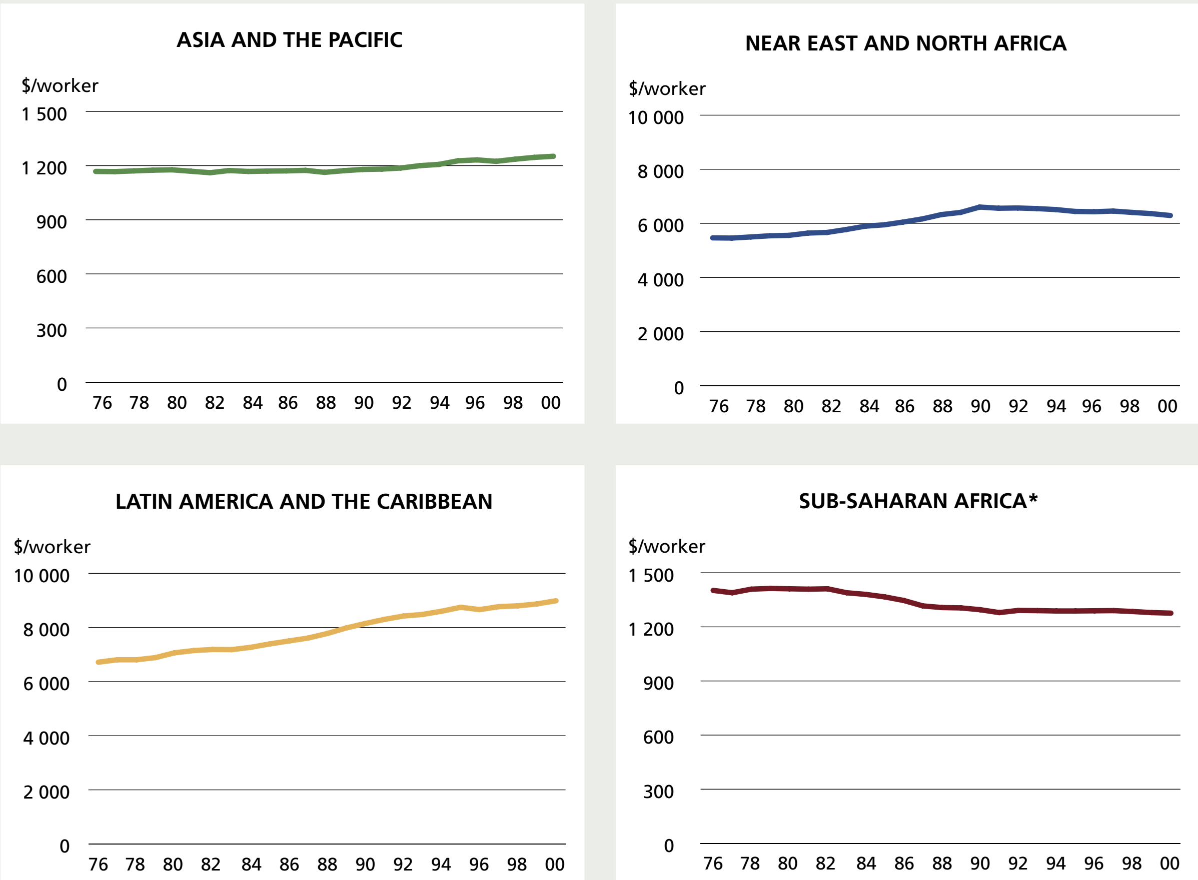


Source: FAO.

8. AGRICULTURAL CAPITAL STOCK[1]

- Agricultural capital stock per agricultural worker differs very significantly among the developing country regions, with levels in Latin America and the Caribbean and in the Near East and North Africa significantly above those in sub-Saharan Africa and in Asia and the Pacific.
- Since 1975, agricultural capital stock per agricultural worker has increased relatively significantly only in Latin America and the Caribbean with only limited increases in percentage terms in the Near East and North Africa and Asia and the Pacific (Figure 35).

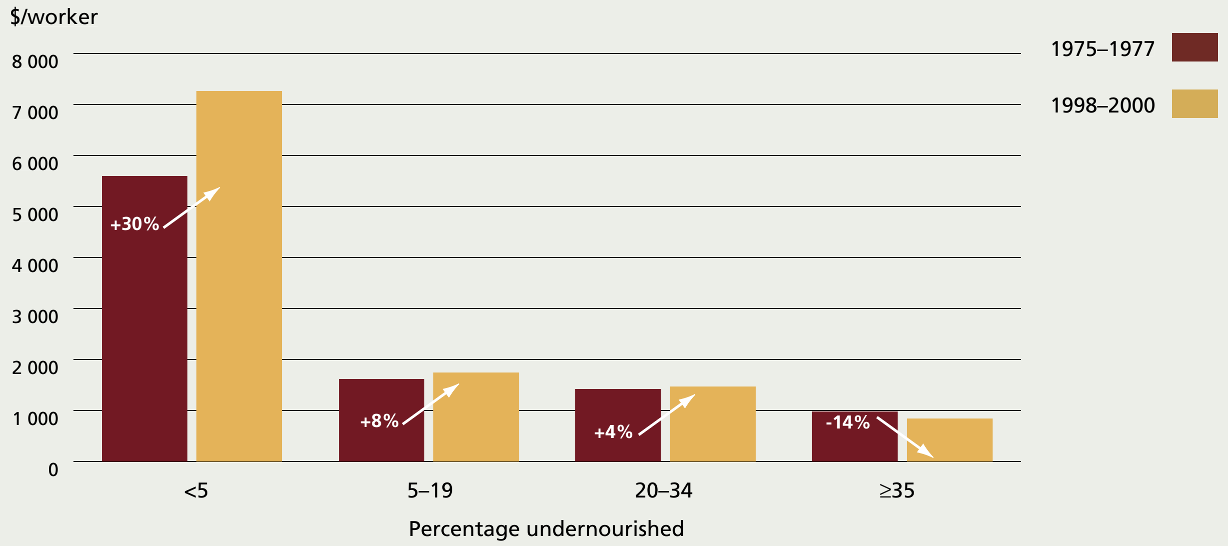
FIGURE 35
Agricultural capital stock per agricultural worker, by region
(At constant 1995 prices)



*Not including South Africa

Source: FAO.

FIGURE 36
Agricultural capital stock per agricultural worker in developing countries by prevalence of undernourishment, 1998–2000
(At constant 1995 prices)



Source: FAO.

- The feature of most concern is the slow, but seemingly inexorable decline in capital stock per agricultural worker in sub-Saharan Africa.

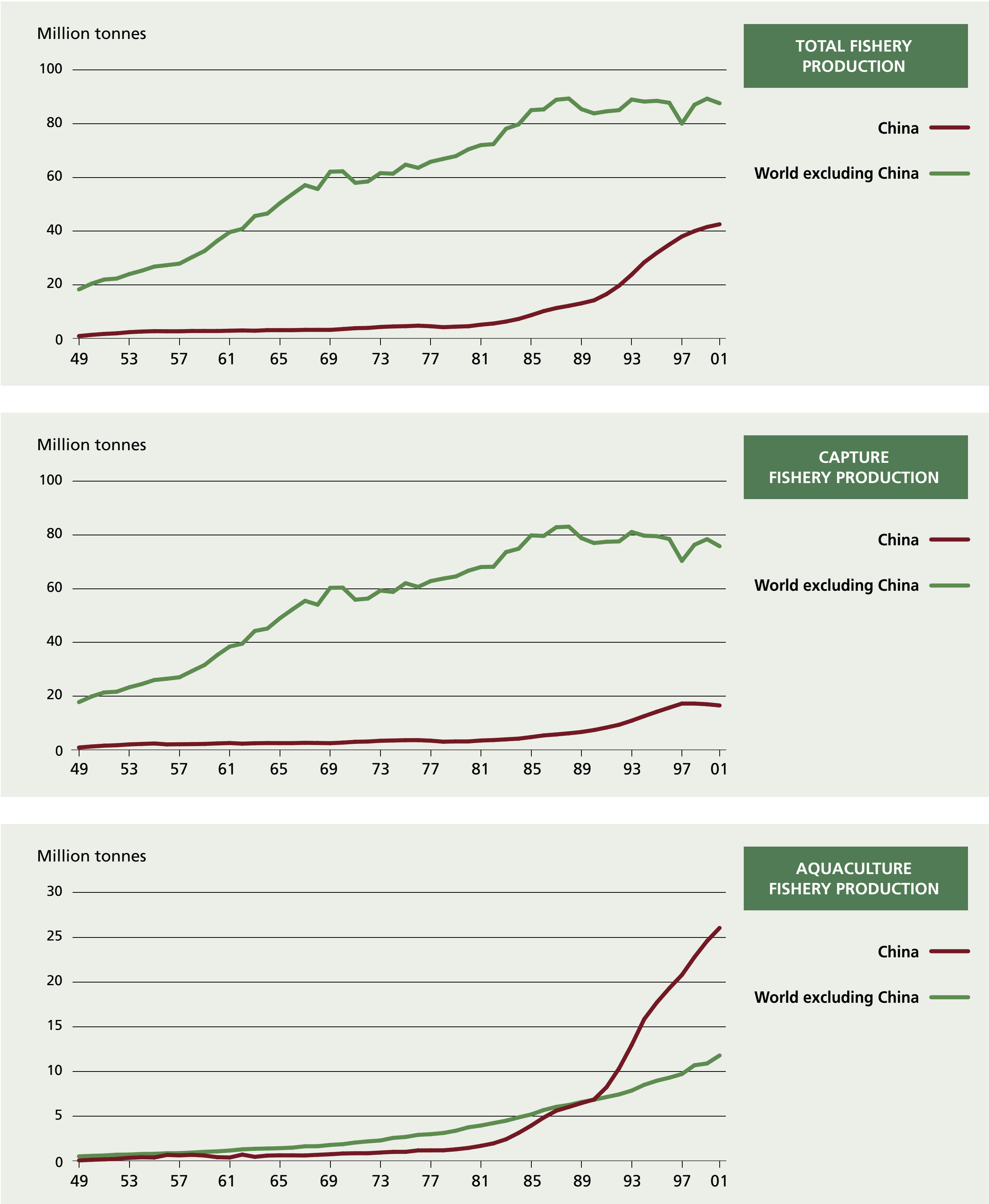
- Relating capital stock per agricultural worker to prevalence of undernourishment shows that countries with the lowest incidence of undernourishment have the highest level of capital stock per agricultural worker and have seen the largest increase over the past 25 years (Figure 36). Countries where more than 35 percent of the population is undernourished have the lowest levels of capital stock per worker and have even experienced a decline over the past 25 years.

[1] The capital stock in agriculture refers to the replacement value in monetary terms (at the end of the year) of tangible fixed assets produced or acquired for repeated use in the agriculture production process over a long period. The estimates of capital stock in agriculture have been derived using physical data on livestock, tractors, irrigated land and land under permanent crops, etc., and the average prices for the year 1995.

9. FISHERIES: PRODUCTION, DISPOSITION AND TRADE

- Total fishery production in 2001 was reported to be 130.2 million tonnes, of which 37.9 million tonnes was from aquaculture (Figure 37).
- World capture fisheries production declined from 95.4 million tonnes in 2000 to 92.4 million tonnes in 2001 (Figure 37). Most of the fluctuations in capture production in recent years have been the result of variations in catches of Peruvian anchoveta, which are driven by climatic conditions (i.e. the "El Niño" phenomenon). Excluding anchoveta, global capture production has remained fairly stable since 1995.
- World aquaculture production has been increasing rapidly in recent years and now accounts for almost 30 percent of total fisheries production (Figure 37). Most of the expansion has been attributable to China, which is now responsible for more than two-thirds of total aquaculture production in volume terms.
- In 2001, about 38 percent (live-weight equivalent) of world fish production entered international trade (Figures 38 and 39). Developing countries supplied slightly more than 50 percent of exports, with the first eight or nine exporters accounting for two-thirds of the developing country total. More than 80 percent of the total world fisheries import value was concentrated in the developed countries, with Japan and the United States accounting for 45 percent of the total.
- In 2001, an estimated about 31 million tonnes of world fishery production were used for reduction to meal, leaving an estimated 99 million tonnes for human consumption.
- In per capita terms, whereas total supplies of fish for food from capture have been stagnating in recent years, per capita supplies from aquaculture have been increasing strongly (Figure 40). This is particularly so in China, where per capita supplies from aquaculture have expanded to the point of providing slightly more than 75 percent of total per capita supplies of fish for food, compared with only 18 percent in the rest of the world.

FIGURE 37
World fish production, China and rest of the world



Source: FAO.

FIGURE 38
Trade in fish and fishery products, developed and developing countries

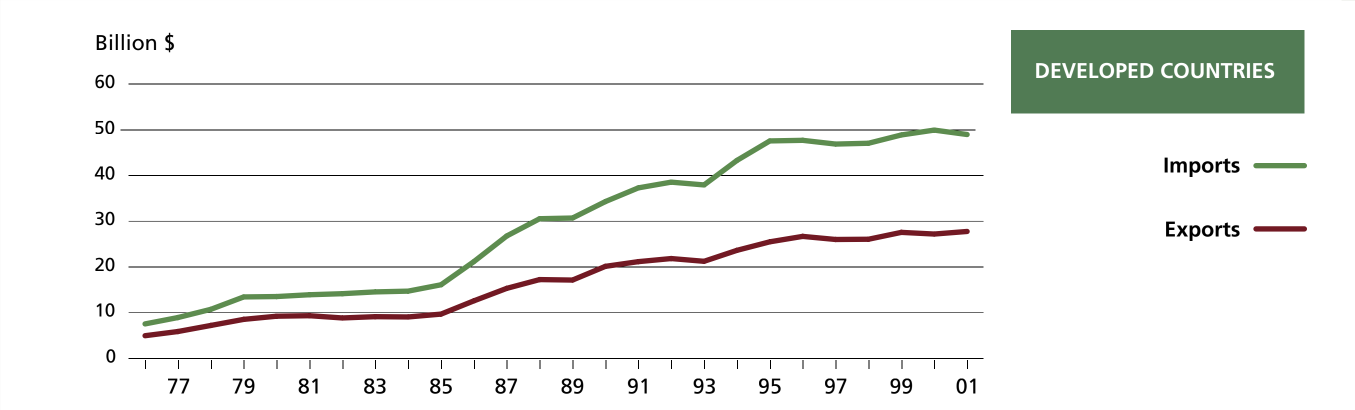
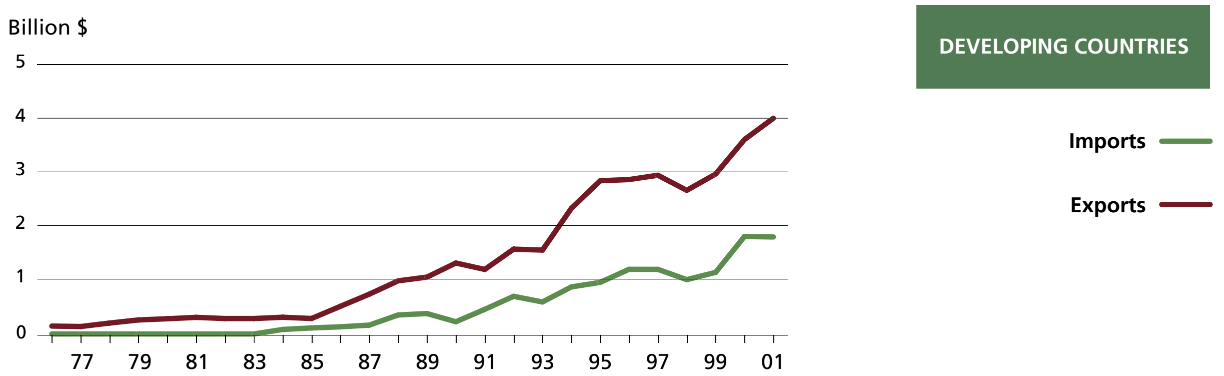
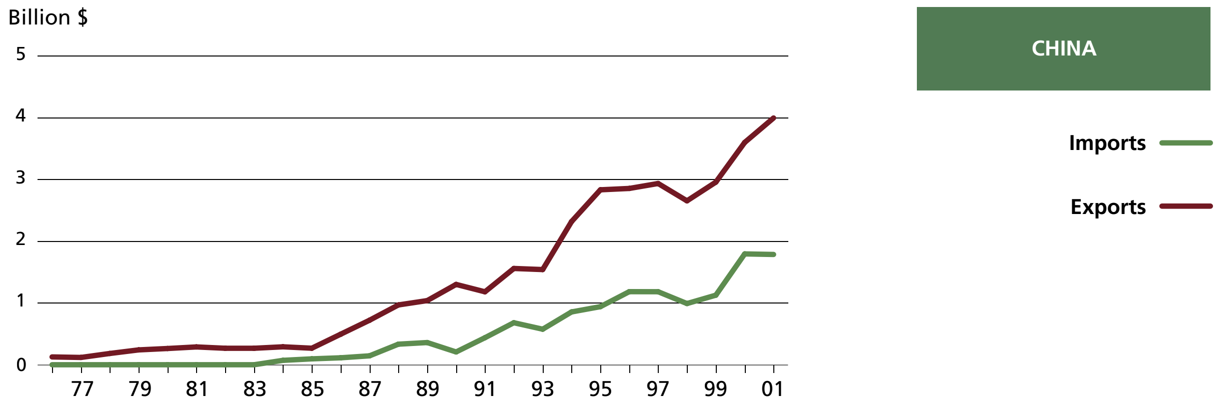
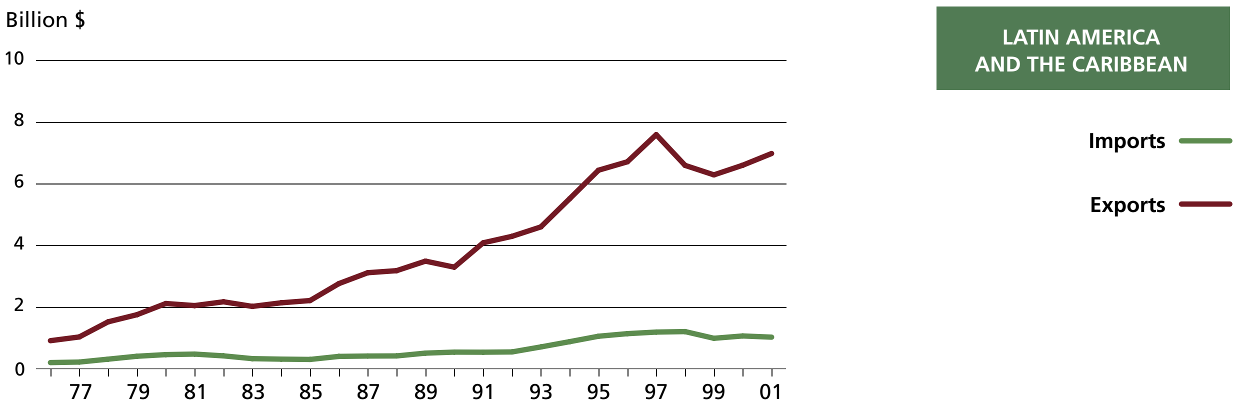


FIGURE 39
Trade in fish and fishery products in developing countries



Source: FAO.



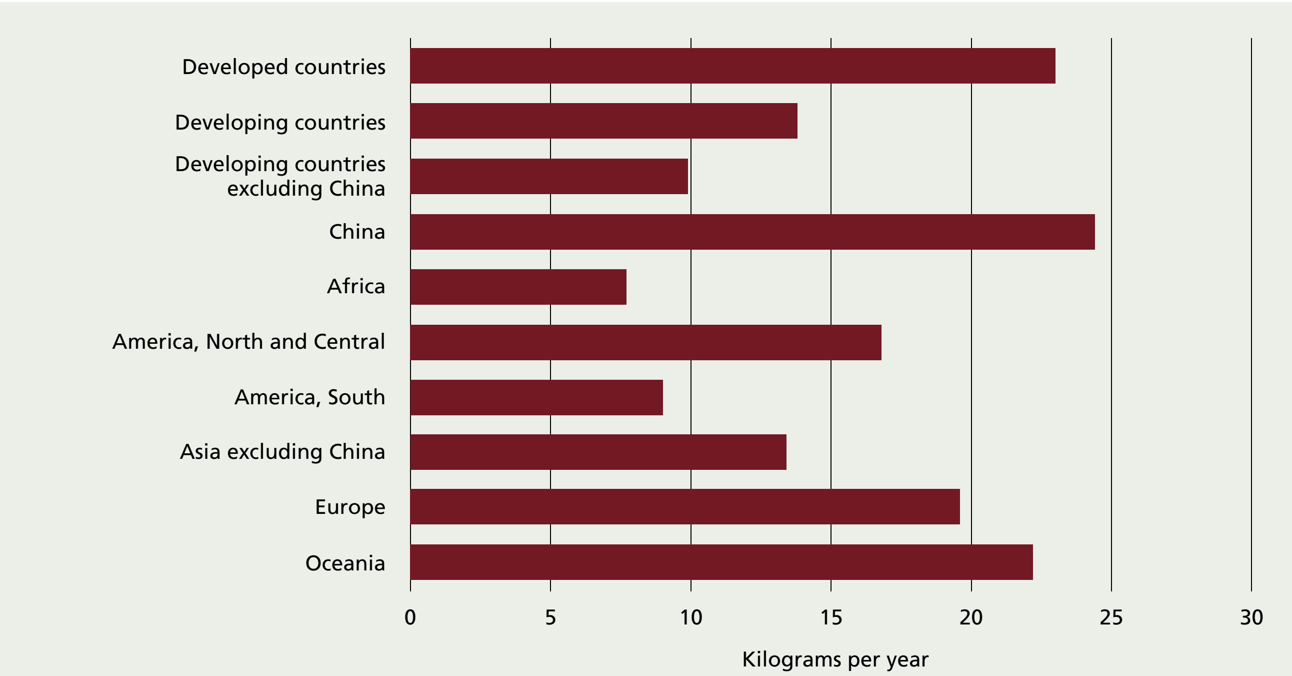


Source: FAO.

FIGURE 40
Per capita fish supply from capture and aquaculture, China and rest of the world

Source: FAO.

FIGURE 41
Per capita fish supply by region, 1997–99



Source: FAO.

10. FORESTRY

- World roundwood production in 2002 reached an estimated 3 380 million cubic metres, about 1.1 percent above the level of the preceding year (Figure 42). Total roundwood production has been stagnant over the last decade, with production in 2002 at about the level of a decade earlier.

- Of total roundwood production in 2002, 47 percent was accounted for by industrial roundwood and 53 percent by woodfuel.

- The larger part of this production, 2 015 million cubic metres or 60 percent of the total in 2002, was accounted for by developing countries (Figure 42).

- In addition, except for 2000 and 2001, production in developing countries has continued on an upward trend throughout the last decade, whereas production in the developed countries, following a significant decline in the early 1990s, is still well below the peak levels of 1989–1990.

- The composition of total roundwood production differs significantly between the developed and the developing country groups. In the developed countries, industrial roundwood accounts for the bulk of production, whereas woodfuel only represents around 15 percent of the total. In the developing countries, almost 80 percent of roundwood production is accounted for by woodfuel, which is continuing on an upward trend.

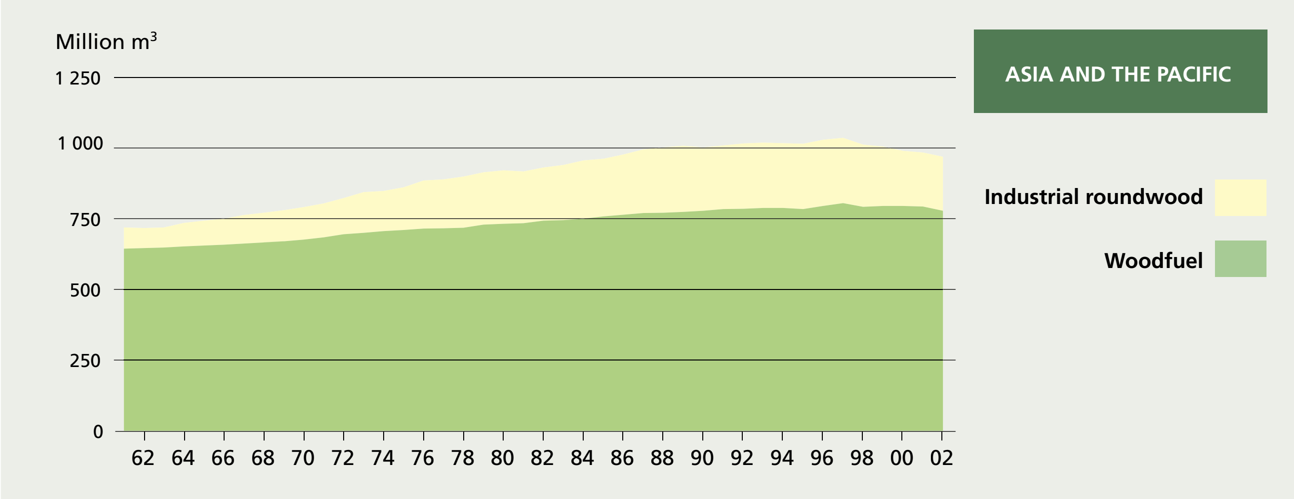
- Thus the larger part of industrial roundwood production continues to be accounted for by the developed countries, which provide more than 70 percent of the total, although the share of developing countries has increased over time.

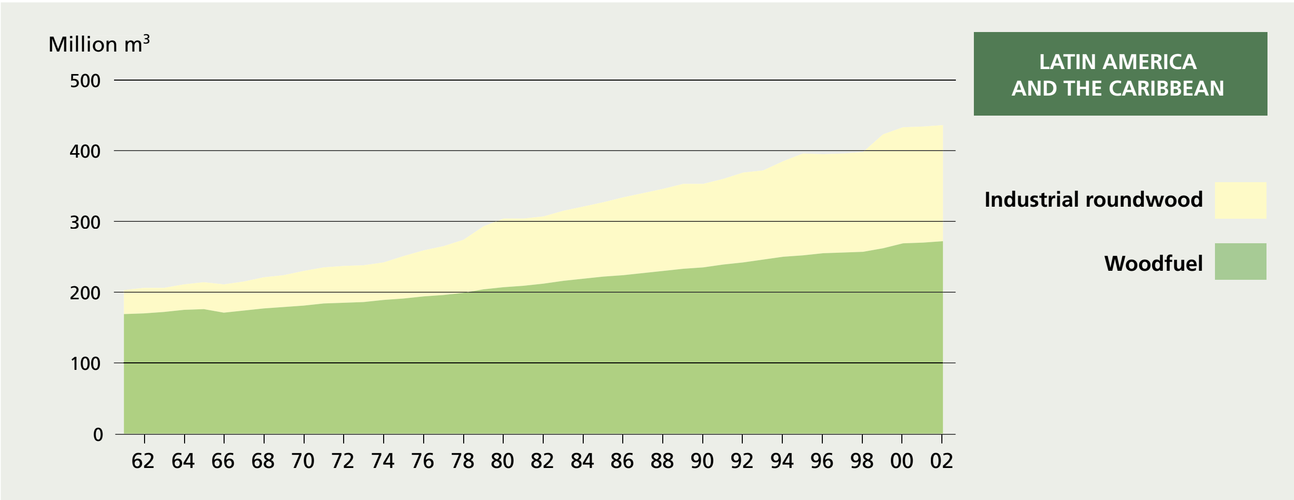
- The Global Forest Resources Assessment 2000 indicated that net annual average loss in global forest cover from 1990 to 2000 was an estimated 9.4 million hectares or 0.2 percent. The largest percentage losses were in Africa and South America (Figure 46).

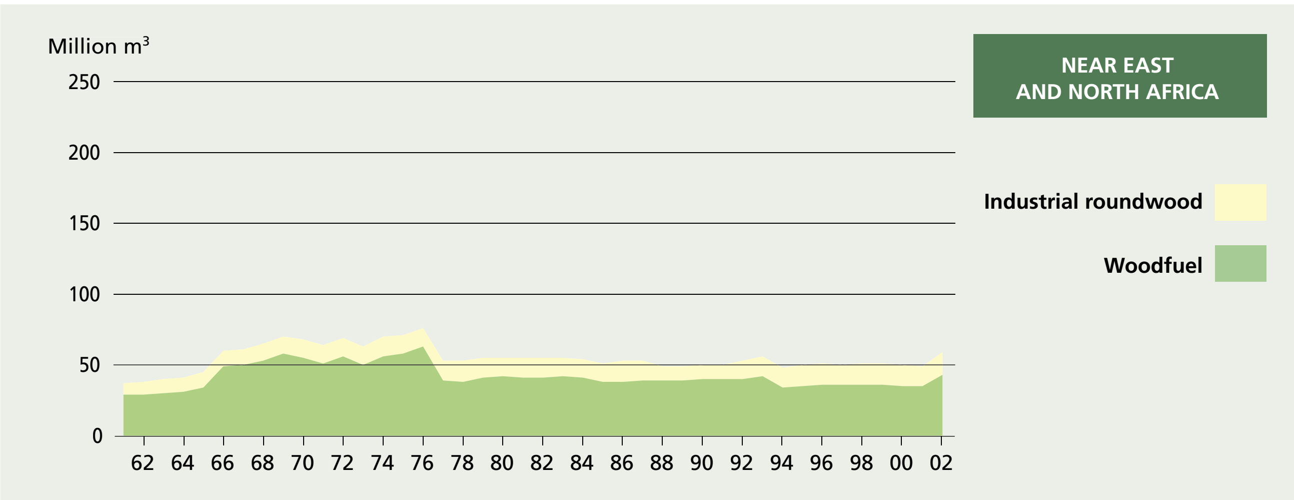
FIGURE 42
World roundwood production

Source: FAO.

FIGURE 43
Roundwood production, by developing country region

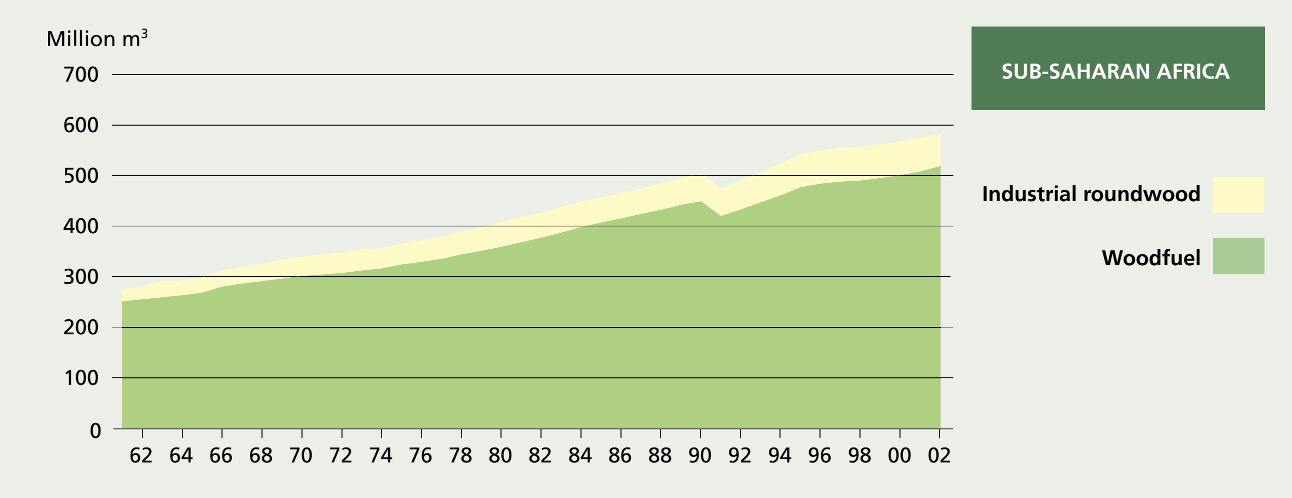






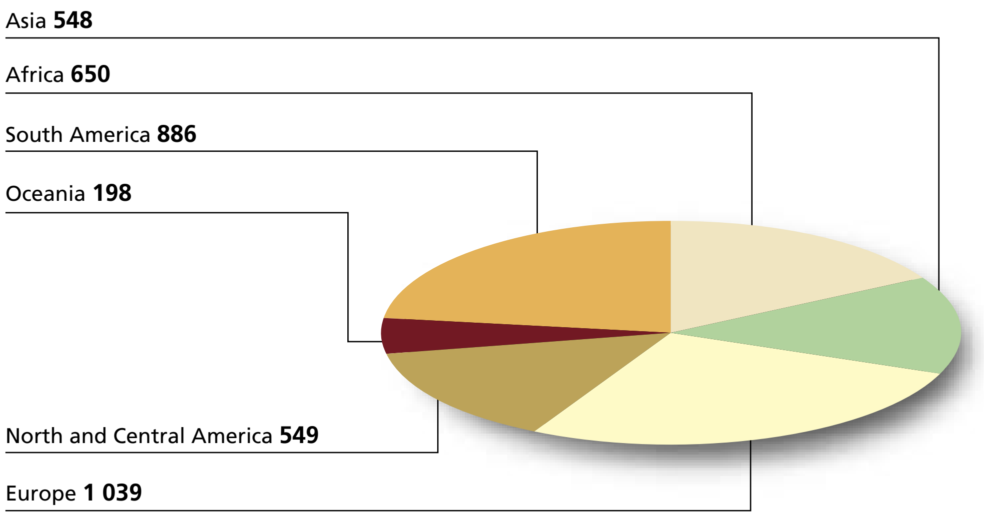
(Cont.)

FIGURE 43 (cont.)
Roundwood production, by developing country region



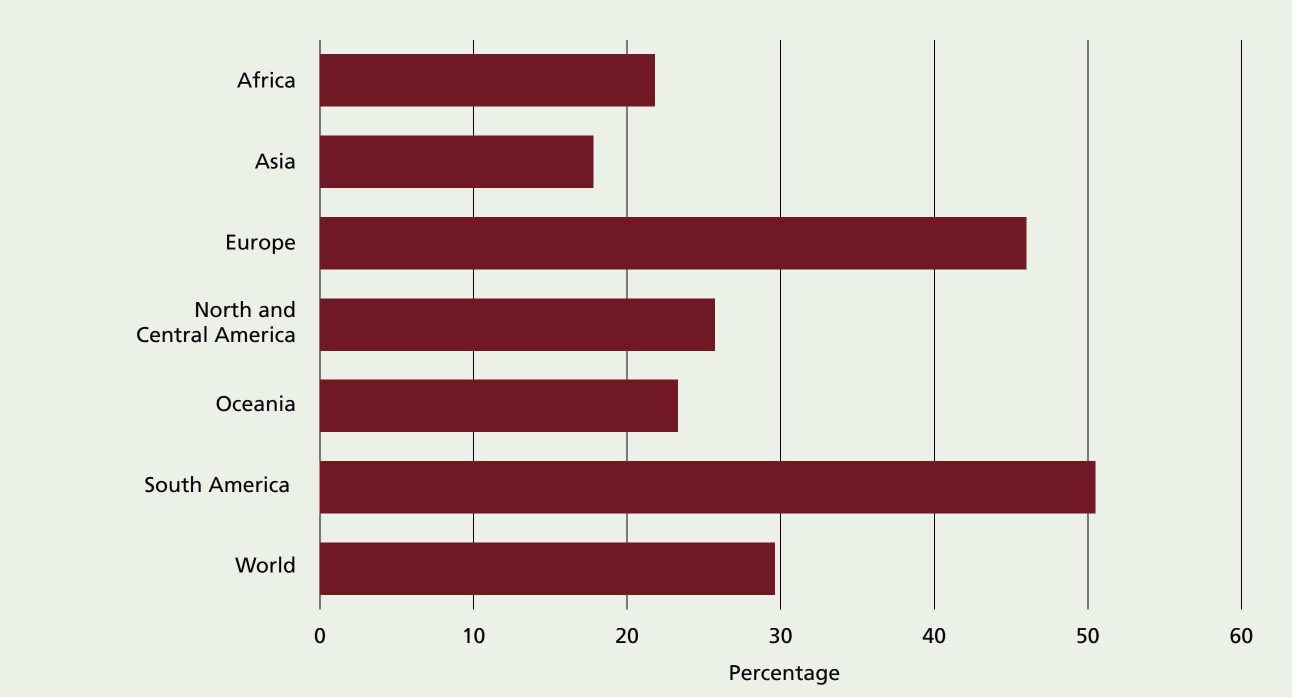
Source: FAO.

FIGURE 44
Forest area in 2000 (million ha)



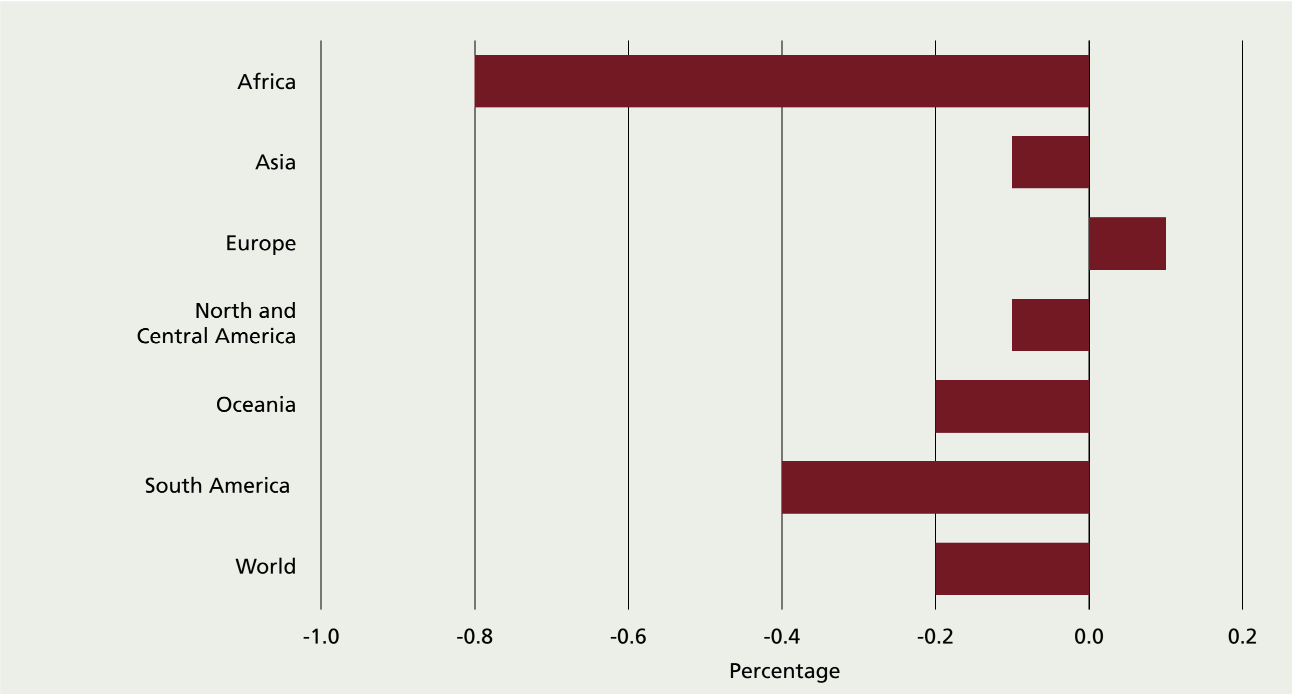
Source: FAO.

FIGURE 45
Share of land area covered by forests in 2000



Source: FAO.

FIGURE 46
Average annual change in forest cover, 1990–2000



Source: FAO.

Part III

STATISTICAL ANNEX

Part III

Notes on the annex tables

Symbols

The following symbols are used in the tables:

...	=	not available
ha	=	hectare
hg/ha	=	hectogram per hectare
hg	=	hectogram
GDP	=	gross domestic product
GNP	=	gross national product
kcal/person/day	=	calories per person per day
kg	=	kilogram
US$	=	US dollar

To divide decimals from whole number a full point (.) is used.

Technical notes

The tables do not include countries for which there were insufficient data.

Numbers displayed in the tables might be slightly different from those obtained from FAOSTAT and the World Development Indicators because of rounding.

1. Food security and nutrition (Table A2)

Source: FAO

Undernourishment

FAO's estimates of the prevalence of undernourishment are based on calculations of the amount of food available in each country (national dietary energy supply or DES) and a measure of inequality in distribution derived from household income or expenditure surveys.

The figures on undernourishment in China, Mainland, include Taiwan Province of China.

For Afghanistan, Iraq and Somalia, the estimates of the proportion of undernourished for 1999–2001 are not available; estimates for 1998–2000 were used instead.

Symbols used

To denote a proportion of less than 2.5 percent undernourished a dash (–) is used.

Dietary energy supply

Per capita supplies in terms of product weight are derived from the total supplies available for human consumption (i.e. food) by dividing the quantities of food by the total population actually partaking of the food supplies during the reference period. Dietary energy supply is weighted by the total population.

Probability of actual consumption falling below 95 percent of trend for 1980–2001

Following Sadoulet and de Janvry (1995), the probability that national consumption falls below a certain percentage α (in these tables α = 95%) of its long-term trend is: $\Pr(C<\alpha\hat{C}_t)$ where $\hat{C}_t$ is the estimated trend consumption. This probability can be estimated by historical data assuming that the error term u_t is normally distributed around the regression line.

Under this hypothesis:

$$\Pr(C<\alpha\hat{C}_t)=\Pr\left[\frac{C-\overline{C}}{\sigma_c}<-\left(\frac{\overline{C}-\alpha\hat{C}_t}{\sigma_c}\right)\right]=$$

$$\Pr\left[u=\frac{C-\hat{C}_t}{\hat{C}_t}<-(1-\alpha)\right]=\Pr\left[\frac{u}{\mathrm{I}_c}<\frac{-(1-\alpha)}{\mathrm{I}_c}\right]=1-F_{(1-\alpha)/\mathrm{I}_c}$$

where $\mathrm{I}_c = \frac{\sigma_c}{\overline{C}_t}$ and F(.) is the standard normal distribution.

Specifically, the apparent consumption is regressed on a non-linear time trend:

$$C_t = a_0 + a_1\mathrm{t} + a_2\mathrm{t}^2 + u_t$$

We bootstrapped both the coefficients a_0 and a_1. Then we worked on the estimated residuals:

$$\hat{u}_t = \begin{cases} = C_t - \hat{a}_0 - \hat{a}_1\mathrm{t} - \hat{a}_2\mathrm{t}^2 & \text{if both the estimated coefficients were statistically different from zero at 5 percent level} \\ = C_t - \overline{C} & \text{otherwise} \end{cases}$$

where $\overline{C}$ represents mean apparent consumption over the time horizon. The assumption of normal distribution for residuals implies an assumption of symmetry. Thus, a 10 percent probability of shortfall on one side is accompanied by a 10 percent probability of consumption in excess of 105 percent of trend.

Coefficient of variation of food consumption

This coefficient is derived from the standard deviation of the variable 100 x ($C_t - C_t$ trend)/C_t trend.

2. Agricultural production and productivity (Table A3)

Source: FAO

Agricultural and per capita food production annual growth rates

The growth rates refer to the level of change of the aggregate volume of production. Production quantities of each commodity are weighted by 1989–91 average international commodity prices and summed for each year.

3. Population and labour force indicators (Table A4)

Source: FAO

Total population

The total population usually refers to the present-in-area (de facto) population, which includes all persons physically present within the current geographical boundaries of countries at the mid-point of the reference period.

Rural population

Usually the urban area is defined and the residual from the total population is taken as rural. In practice, the criteria adopted for distinguishing between urban and rural areas vary among countries.

Agricultural population

The agricultural population is defined as all persons depending for their livelihood on agriculture, hunting, fishing or forestry. This estimate comprises all persons actively engaged in agriculture and their non-working dependants.

Economically active population

This refers to the number of all employed and unemployed persons (including those seeking work for the first time).

Economically active population in agriculture

The economically active population in agriculture is that part of the economically active population engaged in or seeking work in agriculture, hunting, fishing or forestry.

4. Land-use indicators (Table A5)

Source: FAO

Total land area

Total area excluding area under inland water bodies.

Forest and wood area

Land under natural or planted stands of trees, whether productive or not.

Agricultural area

The sum of area under arable land, permanent crops and permanent pastures.

Arable land

Land under temporary crops (double-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market- and kitchen-gardens and land temporarily fallow (less than five years).

Permanent crops area

Land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest.

Permanent pasture area
Land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).

Irrigated area
Data on irrigation relate to areas equipped to provide water to the crops.
- *China*: data on irrigated area cover farmland only (areas under orchard and pastures are excluded).
- *Cuba*: data refer to state sector only.
- *Japan; Republic of Korea; Sri Lanka*: data refer to irrigated rice only.

Fertilizer consumption (use)
Data refer to total fertilizer use. The total estimates are obtained by adding the volumes of nitrogenous, phosphate and potash fertilizers expressed in terms of plant nutrients (N, P_2O_5 and K_2O, respectively).

5. Trade indicators (Table A6)
Source: FAO and World Bank (*World Development Indicators 2003*, CD-ROM and online dataset)

Total merchandise trade
Data refer to the total merchandise trade. In general, export values are f.o.b. (free on board) and import values are c.i.f. (cost, insurance and freight).

Agricultural trade
Data refer to agriculture in the narrow sense, excluding fishery and forestry products.

Food trade
Data refer to food and animals.

Agricultural GDP
The agriculture, value added (percentage of GDP), is derived from World Bank national accounts data, and OECD National Account data files. Agriculture includes forestry, fishing and hunting, as well as cultivation of crops and livestock production.

Agricultural exports relative to agricultural GDP
Agricultural exports relative to agricultural GDP was weighted by agriculture, value added.

6. Economic indicators (Table A7)
Source: World Bank (*World Development Indicators 2003*, CD-ROM and online dataset)
Weighting: GNP per capita (current US$), GDP per capita (annual percentage growth) and GDP per capita, PPP (current international $) were weighted by the total population. GDP (annual percentage growth) and agriculture, value added (percentage of GDP) were weighted by GDP (constant 1995 US$). Agriculture, value added (annual percentage growth) was weighted by agriculture, value

added (constant 1995 US$). Agriculture, value added per worker was weighted by economic active population in agriculture.

National poverty headcount
National poverty rate is the percentage of the population living below the national poverty line. National estimates are based on population-weighted subgroup estimates from household surveys.

GNP per capita (current US$)
GNP per capita is the gross national income, converted to US dollars using the World Bank Atlas method, divided by the mid-year population.

GDP (annual percentage growth)
Annual percentage growth rate of GDP at market prices based on constant local currency. Aggregates are based on constant 1995 US dollars.

GDP per capita (annual percentage growth)
Annual percentage growth rate of GDP per capita based on constant local currency. GDP per capita is the GDP divided by mid-year population.

GDP per capita, PPP (current international $)
GDP per capita based on purchasing power parity (PPP). PPP GDP is gross domestic product converted to international dollars using purchasing power parity rates. An international dollar has the same purchasing power over GDP as the US dollar has in the United States.

Agriculture, value added per worker
Agriculture value added per worker is a measure of agricultural productivity. Value added in agriculture measures the output of the agriculture sector less the value of intermediate inputs. Agriculture comprises value added from forestry, hunting and fishing as well as cultivation of crops and livestock production.

GDP, constant 1995 US$
Data are in constant 1995 US dollars. Dollar figures for GDP are converted from domestic currencies using 1995 official exchange rates.

7. Total factor productivity (Table A8)

Source: FAO

Total factor productivity (TFP) measures the quantity of output divided by a measure of the quantity of inputs used. The approach taken here is to apply data envelopment analysis (DEA) methods to output and input data obtained from FAOSTAT to estimate a Malmquist index of TFP (Malmquist, 1953). The data cover the periods 1961–80 and 1981–2000. The resulting change in total productivity index can be disaggregated into a technology component and a technical efficiency component. A distinct advantage of the Malmquist DEA method is that no information on input prices is required. The data used are as follows: Output is net agricultural production, i.e. excluding seed and feed, in constant (1989–91) 'international dollars'; Inputs are: Land: arable and land under permanent crops; Labour: total population economically active in agriculture; Fertilizer: total consumption (in nutrient-equivalent terms) of nitrogen, potash and phosphates; Livestock: the weighted sum of camels, buffalo, horses, cattle, asses, pigs, sheep, goats and poultry (using the weights suggested by Hayami and Ruttan, 1985); Physical capita: number of tractors in use. We also included the proportion of arable and permanent cropland that is irrigated as well as the ratio of land that is arable and under permanent crops to agricultural area (which also includes permanent pastures).

Country and regional notes

Data for **China** do not include data for Hong Kong Special Administrative Region; Macao, or Taiwan Province of China, unless otherwise noted.

Data are shown for **Belgium** and **Luxembourg** separately whenever possible, but in most cases the data are aggregated in Belgium/Luxembourg.

Data are shown whenever possible for the individual countries formed from the former **Czechoslovakia** – the **Czech Republic** and the **Slovak Republic**. Data before 1993 are shown under Czechoslovakia.

Data are shown for **Eritrea** and **Ethiopia** separately whenever possible, but in most cases before 1992 data on Eritrea and Ethiopia are aggregated in the data for Ethiopia PDR.

In 1991 the **Union of Soviet Socialist Republics** ("USSR" in the table listings) was dissolved into 15 countries (**Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyz Republic, Latvia, Lithuania, Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine** and **Uzbekistan**). Whenever possible, data are shown for the individual countries. Data before 1992 are shown under USSR.

Data for the **Republic of Yemen** refer to that country from 1990 onward; data for previous years refer to aggregated data of the former People's Democratic Republic of Yemen and the former Yemen Arab Republic unless otherwise noted.

Whenever possible, data are shown for the individual countries formed from the **former Yugoslavia** ("Yugoslavia SFR" in the table listings) – **Bosnia and Herzegovina, Croatia,** the **former Yugoslav Republic of Macedonia, Slovenia** and the **Federal Republic of Yugoslavia**. All references to the Federal Republic of Yugoslavia in the tables are to the **Federal Republic of Yugoslavia (Serbia–Montenegro)**. Data for the years prior to 1992 are shown under Yugoslavia SFR.

TABLE A1
Countries and territories used for statistical purposes in this publication

Developing countries				Developed countries	
Asia and the Pacific/ Far East and Oceania	**Latin America and the Caribbean**	**Near East and North Africa**	**Sub-Saharan Africa**	**Developed market economies**	**Countries in transition**
American Samoa	Anguilla	Afghanistan	Angola	Andorra	Albania
Bangladesh	Antigua and Barbuda	Algeria	Benin	Australia	Armenia
Bhutan	Argentina	Bahrain	Botswana	Austria	Azerbaijan
British Virgin Islands	Aruba	Cyprus	Burkina Faso	Belgium-Luxembourg	Belarus
Brunei Darussalam	Bahamas	Egypt	Burundi	Canada	Bosnia and Herzegovina
Cambodia	Barbados	Iran, Islamic Republic of	Cameroon	Denmark	Bulgaria
China, Hong Kong SAR	Belize	Iraq	Cape Verde	Faeroe Islands	Croatia
China, Macao SAR	Bermuda	Jordan	Central African Republic	Finland	Czech Republic
China, Mainland	Bolivia	Kuwait	Chad	France	Estonia
China, Taiwan Prov. of	Brazil	Lebanon	Comoros	Germany	Georgia
Cocos (Keeling) Islands	Cayman Islands	Libyan Arab Jamahiriya	Congo, Dem. Republic of the	Gibraltar	Hungary
Cook Islands	Chile	Morocco	Congo, Republic of the	Greece	Kazakhstan
Fiji	Colombia	Oman	Côte d'Ivoire	Greenland	Kyrgyzstan
French Polynesia	Costa Rica	Palestine, Occupied Territory	Djibouti	Iceland	Latvia
Guam	Cuba	Qatar	Equatorial Guinea	Ireland	Lithuania
India	Dominica	Saudi Arabia	Eritrea	Israel	Macedonia, The Former Yugoslav Republic of
Indonesia	Dominican Rep.	Syrian Arab Republic	Ethiopia	Italy	Moldova, Republic of
Kiribati	Ecuador	Tunisia	Gabon	Japan	Poland
Korea, Dem. People's Rep. of	El Salvador	Turkey	Gambia	Liechtenstein	Romania
Korea, Republic of	Falkland Islands (Malvinas)	United Arab Emirates	Ghana	Malta	Russian Federation
Lao People's Dem. Rep. of	French Guiana	Yemen	Guinea	Monaco	Slovakia
Malaysia	Grenada		Guinea-Bissau	Netherlands	Slovenia
Maldives	Guadeloupe		Kenya	New Zealand	Tajikistan
Marshall Islands	Guatemala		Lesotho	Norway	Turkmenistan
Micronesia, Fed. States of	Guyana		Liberia	Portugal	Ukraine
Mongolia	Haiti		Madagascar	Saint Pierre and Miquelon	Uzbekistan
Myanmar	Honduras		Malawi	San Marino	Yugoslavia
Nauru	Jamaica		Mali	Spain	
Nepal	Martinique		Mauritania	Sweden	
New Caledonia	Mexico		Mauritius	Switzerland	
Niue	Montserrat		Mozambique	United Kingdom	
Norfolk Island	Netherlands Antilles		Namibia	United States of America	

TABLE A1 *(cont.)*

Developing countries				Developed countries	
Asia and the Pacific / Far East and Oceania	**Latin America and the Caribbean**	**Near East and North Africa**	**Sub-Saharan Africa**	**Developed market economies**	**Countries in transition**
Northern Marianas Islands	Nicaragua		Niger		
Pakistan	Panama		Nigeria		
Palau	Paraguay		Réunion		
Papua New Guinea	Peru		Rwanda		
Philippines	Puerto Rico		Saint Helena		
Samoa	Saint Kitts and Nevis		Sao Tome and Principe		
Singapore	Saint Lucia		Senegal		
Solomon Islands	Saint Vincent and the Grenadines		Seychelles		
Sri Lanka	Suriname		Sierra Leone		
Thailand	Trinidad and Tobago		Somalia		
Timor-Leste	Turks and Caicos Islands		South Africa		
Tokelau	United States Virgin Islands		Sudan		
Tonga	Uruguay		Swaziland		
Tuvalu	Venezuela		Tanzania, United Rep. of		
Vanuatu			Togo		
Viet Nam			Uganda		
Wallis and Futuna Islands			Zambia		
			Zimbabwe		

Note: South Africa is included in sub-Saharan Africa and not in the developed countries.

TABLE A2
Food security and nutrition

	Number of people undernourished (Millions)		Proportion of undernourished in total population (%)		Dietary energy supply in total population (kcal/person/day)		Dietary energy supply in total population (Average annual % increase)	Coefficient of variation of food consumption	Probability of actual consumption falling below 95% of trend (%)
	1990–92	1999–2001	1990–92	1999–2001	1990–92	1999–2001	1990–2001	1980–2001	1980–2001
WORLD	**...**	**...**	**...**	**...**	**2 705**	**2 803**	**0.28**	**...**	**...**
DEVELOPED COUNTRIES	**...**	**...**	**...**	**...**	**3 273**	**3 273**	**–0.07**	**...**	**...**
DEVELOPING COUNTRIES	**816.6**	**797.9**	**20**	**17**	**2 535**	**2 677**	**0.49**	**...**	**...**
ASIA AND THE PACIFIC	**566.8**	**505.2**	**20**	**16**	**2 522**	**2 702**	**0.61**	**4.8**	**13.9**
Bangladesh	39.2	44.1	35	32	2 074	2 156	0.61	2.6	2.7
Brunei Darussalam	...	...	...	...	2 760	2 771	–0.01	...	...
Cambodia	4.3	5.0	43	38	1 871	1 973	0.88	6.4	21.7
China, Hong Kong SAR	0.0	0.1	–	–	3 228	3 099	–0.53	...	...
China, Macao SAR	...	...	...	...	2 716	2 509	–0.35	...	...
China, Mainland	193.0	135.3	17	11	2 701	2 972	0.98	4.4	12.7
China, Taiwan Province of	...	...	...	...	2 966	3 059	0.41	...	...
Fiji Islands	...	...	...	...	2 638	2 782	0.72	...	...
French Polynesia	...	...	...	...	2 864	2 881	0.16	...	...
India	214.5	213.7	25	21	2 368	2 492	0.30	5.2	17.0
Indonesia	16.6	12.6	9	6	2 694	2 903	0.90	1.2	0.0
Kiribati	...	...	...	...	2 653	2 917	1.36	3.2	6.4
Korea, Democratic People's Rep. of	3.7	7.5	18	34	2 452	2 176	–0.06	3.2	6.5
Korea, Rep. of	0.8	0.7	–	–	3 005	3 074	–0.04	...	...
Lao People's Dem. Rep.	1.2	1.2	29	22	2 113	2 282	0.78	1.9	0.3
Malaysia	0.6	0.5	3	–	2 782	2 916	0.78	...	...
Maldives	...	...	...	...	2 387	2 561	0.74	3.8	9.5
Mongolia	0.8	1.0	34	38	2 062	2 068	–0.82	5.7	18.6
Myanmar	4.0	3.2	10	7	2 636	2 813	0.69	...	...
Nepal	3.4	3.8	18	17	2 396	2 442	0.05	4.0	11.1
New Caledonia	...	...	...	...	2 792	2 769	–0.15	...	...
Pakistan	29.0	26.8	26	19	2 282	2 458	0.36	6.8	23.1
Papua New Guinea	0.9	1.3	25	27	2 208	2 176	–0.10	8.3	27.4
Philippines	16.1	16.8	26	22	2 266	2 374	0.28	5.1	16.2
Solomon Islands	...	...	...	...	2 016	2 236	0.56	8.1	28.2
Sri Lanka	5.0	4.6	29	25	2 202	2 328	0.16	3.2	5.7
Thailand	15.6	11.9	28	19	2 244	2 466	0.84	...	...
Vanuatu	...	...	...	...	2 538	2 575	0.05	9.0	28.9
Viet Nam	18.1	15.1	27	19	2 252	2 501	1.19	...	...

TABLE A2 *(cont.)*

	Number of people undernourished *(Millions)*		Proportion of undernourished in total population *(%)*		Dietary energy supply in total population *(kcal/person/day)*		*(Average annual % increase)*	Coefficient of variation of food consumption	Probability of actual consumption falling below 95% of trend *(%)*
	1990–92	1999–2001	1990–92	1999–2001	1990–92	1999–2001	1990–2001	1980–2001	1980–2001
LATIN AMERICA AND THE CARIBBEAN	**59.0**	**53.4**	**13**	**10**	**2 707**	**2 842**	**0.47**	**5.1**	**13.4**
Antigua and Barbuda	...	...	...	...	2 486	2 367	–0.26	...	...
Argentina	0.7	0.4	–	–	2 993	3 178	0.54	...	...
Bahamas	...	...	...	...	2 620	2 725	–0.02	...	...
Barbados	...	...	...	...	3 080	2 959	–0.42	...	...
Belize	...	...	...	...	2 687	2 863	1.09	...	...
Bermuda	...	...	...	...	2 945	2 946	–0.03	...	...
Bolivia	1.8	1.8	26	22	2 141	2 236	0.44	2.0	0.6
Brazil	18.6	15.6	12	9	2 811	3 002	0.59	...	...
Chile	1.1	0.6	8	4	2 612	2 851	1.24	...	...
Colombia	6.1	5.7	17	13	2 435	2 572	0.70	...	...
Costa Rica	0.2	0.2	7	6	2 683	2 758	0.20	...	...
Cuba	0.9	1.3	8	11	2 697	2 607	–0.93	11.4	33.1
Dominica	...	...	...	...	2 992	2 981	0.04	...	...
Dominican Republic	1.9	2.1	27	25	2 260	2 323	0.06	...	...
Ecuador	0.9	0.6	8	4	2 508	2 735	0.97	...	...
El Salvador	0.6	0.8	12	14	2 492	2 460	0.40	...	...
Grenada	...	...	...	...	2 682	2 742	0.37	...	...
Guatemala	1.4	2.9	16	25	2 352	2 160	–0.18	5.9	20.0
Guyana	0.2	0.1	21	14	2 350	2 536	0.46	...	...
Haiti	4.6	4.0	65	49	1 781	2 041	1.40	4.3	10.9
Honduras	1.1	1.3	23	20	2 313	2 398	0.36	1.6	0.1
Jamaica	0.3	0.2	14	9	2 503	2 690	0.34	...	...
Mexico	4.6	5.2	5	5	3 107	3 152	0.23	...	...
Netherlands Antilles	...	...	...	...	2 523	2 581	0.15	...	...
Nicaragua	1.2	1.5	30	29	2 215	2 247	0.00	5.0	16.0
Panama	0.5	0.7	20	26	2 339	2 252	0.65	...	...
Paraguay	0.8	0.7	18	13	2 393	2 560	0.09	...	...
Peru	8.9	2.9	40	11	1 979	2 602	1.57	...	...
Saint Kitts and Nevis	...	...	...	...	2 576	2 977	1.20	...	...
Saint Lucia	...	...	...	...	2 735	2 921	0.64	...	...
Saint Vincent and the Grenadines	...	...	...	...	2 393	2 638	0.83	...	...
Suriname	0.1	0.0	13	11	2 548	2 630	0.75	...	...
Trinidad and Tobago	0.2	0.2	13	12	2 638	2 714	0.21	...	...
Uruguay	0.2	0.1	6	3	2 662	2 841	1.11	...	...
Venezuela	2.3	4.4	11	18	2 465	2 331	0.21	...	...

TABLE A2 *(cont.)*

	Number of people undernourished (Millions)		Proportion of undernourished in total population (%)		Dietary energy supply in total population (kcal/person/day)		(Average annual % increase)	Coefficient of variation of food consumption	Probability of actual consumption falling below 95% of trend (%)
	1990–92	1999–2001	1990–92	1999–2001	1990–92	1999–2001	1990–2001	1980–2001	1980–2001
NEAR EAST AND NORTH AFRICA	**25.3**	**40.9**	**8**	**10**	**2 972**	**2 951**	**–0.17**	**5.2**	**10.7**
Afghanistan	8.4	15.3	58	70	1 818	1 673	–2.13	13.8	35.8
Algeria	1.3	1.7	5	6	2 932	2 965	0.25	...	...
Cyprus	...	...	...	...	3 127	3 264	0.81	...	...
Egypt	2.7	2.3	5	3	3 174	3 366	0.71	...	...
Iran, Islamic Republic of	2.8	3.8	5	5	2 886	2 933	0.33	...	...
Iraq	1.2	6.2	7	27	2 657	2 191	–3.39	...	...
Jordan	0.1	0.3	4	6	2 826	2 736	0.15	...	...
Kuwait	0.5	0.1	22	4	2 293	3 151	1.16	...	...
Lebanon	0.1	0.1	3	3	3 151	3 166	0.17	...	...
Libyan Arab Jamahiriya	0.0	0.0	–	–	3 274	3 316	0.19	...	...
Morocco	1.5	2.1	6	7	3 017	3 002	0.19	2.7	3.1
Saudi Arabia	0.6	0.6	4	3	2 771	2 837	0.41	1.7	0.2
Syrian Arab Republic	0.6	0.6	5	4	2 834	3 043	0.74	...	...
Tunisia	0.1	0.1	–	–	3 173	3 344	0.43	...	...
Turkey	1.0	1.8	–	3	3 509	3 357	–0.45	...	...
United Arab Emirates	0.1	0.0	4	–	2 969	3 332	0.87	...	...
Yemen	4.2	6.1	35	33	2 036	2 046	–0.42	2.8	3.8
SUB-SAHARAN AFRICA	**165.5**	**198.4**	**35**	**33**	**2 185**	**2 255**	**0.45**	**7.1**	**19.4**
Angola	6.1	6.4	61	49	1 734	1 903	1.08	4.8	19.3
Benin	1.0	1.0	20	16	2 334	2 481	0.59	16.6	38.2
Botswana	0.2	0.4	18	24	2 355	2 270	0.08	...	...
Burkina Faso	2.0	1.9	22	17	2 334	2 464	1.02	5.1	14.3
Burundi	2.8	4.5	49	70	1 886	1 609	–0.73	12.5	33.5
Cameroon	3.9	4.0	33	27	2 123	2 240	0.54	3.3	7.4
Cape Verde	...	...	...	...	3 086	3 295	0.90	3.8	9.1
Central African Republic	1.5	1.6	50	44	1 875	1 955	0.34	5.6	20.7
Chad	3.5	2.7	58	34	1 781	2 143	2.50	3.2	5.9
Comoros	...	...	...	...	1 915	1 753	–0.61	3.0	4.9
Congo, Democratic Republic of the	12.1	38.3	31	75	2 175	1 566	–2.97	10.5	31.7
Congo, Republic of the	0.9	0.9	37	30	2 089	2 214	0.07	11.4	33.1
Côte d'Ivoire	2.4	2.4	18	15	2 457	2 586	0.52	4.9	17.4
Djibouti	...	...	...	...	1 884	2 161	1.43	7.0	23.6

TABLE A2 *(cont.)*

	Number of people undernourished (Millions)		Proportion of undernourished in total population (%)		Dietary energy supply in total population (kcal/person /day)		(Average annual % increase)	Coefficient of variation of food consumption	Probability of actual consumption falling below 95% of trend (%)
	1990–92	1999–2001	1990–92	1999–2001	1990–92	1999–2001	1990–2001	1980–2001	1980–2001
Eritrea	...	2.2	...	61	...	1 667	...	5.9	19.9
Ethiopia	...	26.4	...	42	...	1 908	...	9.4	29.7
Ethiopia PDR	...	...	...	...	1 684	...	...	...	...
Gabon	0.1	0.1	11	7	2 462	2 580	0.37	...	...
Gambia	0.2	0.4	22	27	2 380	2 282	–0.24	7.8	26.0
Ghana	5.5	2.4	35	12	2 094	2 621	2.58	27.5	42.8
Guinea	2.5	2.3	40	28	2 092	2 327	1.56	5.4	19.7
Guinea-Bissau	...	...	...	...	2 485	2 440	0.42	3.9	10.0
Kenya	10.6	11.5	44	37	1 924	2 044	0.18	4.1	10.8
Lesotho	0.5	0.5	27	25	2 268	2 307	0.28	1.3	0.0
Liberia	0.7	1.2	33	42	2 224	2 080	–2.01	9.9	30.7
Madagascar	4.3	5.7	35	36	2 085	2 069	–0.19	4.1	11.3
Malawi	4.7	3.7	49	33	1 886	2 164	0.95	3.7	8.8
Mali	2.2	2.4	25	21	2 296	2 371	0.20	4.3	12.0
Mauritania	0.3	0.3	14	10	2 606	2 733	0.57	2.4	1.7
Mauritius	0.1	0.1	6	5	2 894	2 982	0.68	...	...
Mozambique	9.7	9.7	69	53	1 708	1 945	1.12	6.4	23.4
Namibia	0.3	0.1	20	7	2 292	2 698	1.98	...	...
Niger	3.3	3.7	42	34	2 006	2 128	0.28	3.9	9.9
Nigeria	11.2	9.1	13	8	2 559	2 768	1.54	18.4	39.3
Rwanda	2.8	3.1	43	41	1 957	1 992	0.54	13.6	35.5
Sao Tome and Principe	...	...	...	...	2 313	2 464	1.07	11.5	33.2
Senegal	1.7	2.3	23	24	2 283	2 275	0.50	4.9	15.3
Seychelles	...	...	...	...	2 344	2 433	0.25	...	...
Sierra Leone	1.9	2.2	46	50	1 996	1 928	–0.03	5.6	18.8
Somalia	4.9	6.2	68	71	1 638	1 679	–0.69	9.9	30.7
South Africa	...	...	...	...	2 870	2 894	0.36	...	...
Sudan	7.9	7.7	31	25	2 168	2 290	0.51	5.2	16.6
Swaziland	0.1	0.1	10	12	2 606	2 565	0.05	2.7	3.2
Tanzania, United Republic of	9.5	15.2	35	43	2 078	1 970	–0.77	6.1	20.5
Togo	1.2	1.1	33	25	2 153	2 315	0.55	6.1	21.3
Uganda	4.1	4.5	23	19	2 291	2 371	0.15	6.4	23.0
Zambia	3.7	5.2	45	50	1 965	1 900	–0.61	2.8	3.6
Zimbabwe	4.5	4.9	43	39	2 015	2 095	–0.11	...	...
DEVELOPED MARKET ECONOMIES	**...**	**...**	**...**	**...**	**3 330**	**3 459**	**0.42**	**...**	**...**
Australia	...	...	...	...	3 176	3 109	–0.22	...	...
Austria	...	...	...	...	3 519	3 788	0.78	...	...

TABLE A2 *(cont.)*

	Number of people undernourished *(Millions)*		Proportion of undernourished in total population *(%)*		Dietary energy supply in total population *(kcal/person/day)*		*(Average annual % increase)*	Coefficient of variation of food consumption	Probability of actual consumption falling below 95% of trend *(%)*
	1990–92	1999–2001	1990–92	1999–2001	1990–92	1999–2001	1990–2001	1980–2001	1980–2001
Belgium/ Luxembourg	...	...	...	...	3 579	3 674	0.38	...	...
Canada	...	...	...	...	3 021	3 176	0.46	...	...
Denmark	...	...	...	...	3 227	3 437	0.66	...	...
Finland	...	...	...	...	3 145	3 183	–0.05	...	...
France	...	...	...	...	3 535	3 603	0.16	...	...
Germany	...	...	...	...	3 398	3 499	0.30	...	...
Greece	...	...	...	...	3 563	3 730	0.30	...	...
Iceland	...	...	...	...	3 095	3 206	0.24	...	...
Ireland	...	...	...	...	3 629	3 691	0.13	...	...
Israel	...	...	...	...	3 390	3 518	0.27	...	...
Italy	...	...	...	...	3 591	3 665	0.29	...	...
Japan	...	...	...	...	2 812	2 753	–0.28	...	...
Malta	...	...	...	...	3 239	3 511	0.52	...	...
Netherlands	...	...	...	...	3 352	3 294	0.27	...	...
New Zealand	...	...	...	...	3 217	3 211	0.25	...	...
Norway	...	...	...	...	3 181	3 366	0.53	...	...
Portugal	...	...	...	...	3 441	3 749	1.02	...	...
Spain	...	...	...	...	3 307	3 405	0.55	...	...
Sweden	...	...	...	...	2 987	3 137	0.52	...	...
Switzerland	...	...	...	...	3 307	3 382	0.30	...	...
United Kingdom	...	...	...	...	3 218	3 343	0.43	...	...
United States of America	...	...	...	...	3 516	3 769	0.80	...	...
	1993–95	1999–2001	1993–95	1999–2001	1993–95	1999–2001	1993–2001		
COUNTRIES IN TRANSITION	**25.2**	**33.6**	**6**	**8**	**2 939**	**2 886**	**–0.23**	**...**	**...**
Albania	0.2	0.1	5	4	2 888	2 943	1.61	...	...
Armenia	2.0	1.9	55	51	1 926	2 001	1.95	...	...
Azerbaijan	2.8	1.7	37	21	2 109	2 382	0.92	...	...
Belarus	0.1	0.3	–	3	3 163	2 964	–0.83	...	...
Bosnia and Herzegovina	0.5	0.3	13	8	2 582	2 731	2.01	...	...
Bulgaria	0.7	1.3	8	16	2 891	2 626	–1.86	...	...
Croatia	0.8	0.5	18	12	2 486	2 619	0.74	...	...
Czech Republic	0.2	0.2	–	–	3 074	3 082	...	...	...
Estonia	0.2	0.1	10	4	2 706	3 021	2.05	...	...
Georgia	2.4	1.4	45	26	2 042	2 285	0.81	...	...
Hungary	0.1	0.0	–	–	3 343	3 498	–0.24	...	...
Kazakhstan	0.2	3.5	–	22	3 256	2 362	–1.76	...	...

TABLE A2 *(cont.)*

	Number of people undernourished		Proportion of undernourished in total population		Dietary energy supply in total population			Coefficient of variation of food consumption	Probability of actual consumption falling below 95% of trend
	(Millions)		*(%)*		*(kcal/person /day)*		*(Average annual % increase)*		*(%)*
	1993–95	1999–2001	1993–95	1999–2001	1993–95	1999–2001	1993–2001		
Kyrgyzstan	1.3	0.4	28	7	2 263	2 857	1.90	...	...
Latvia	0.1	0.2	3	6	2 966	2 786	–0.30	...	...
Lithuania	0.2	0.0	4	–	2 894	3 262	1.41	...	...
Macedonia, The Former Yugoslav Republic of	0.3	0.2	15	10	2 526	2 662	0.48	...	...
Moldova, Republic of	0.2	0.5	5	12	2 930	2 682	–1.85	...	...
Poland	0.3	0.3	–	–	3 337	3 385	0.15	...	...
Romania	0.4	0.2	–	–	3 209	3 340	1.61	...	...
Russian Federation	6.4	6.2	4	4	2 925	2 944	0.35	...	...
Serbia–Montenegro	0.5	0.9	5	9	2 901	2 717	–1.05	...	...
Slovakia	0.2	0.2	4	5	2 917	2 905	...	...	...
Slovenia	0.1	0.0	3	–	2 942	3 057	0.74	...	...
Tajikistan	1.2	4.3	22	71	2 304	1 716	–3.67	...	...
Turkmenistan	0.6	0.3	15	7	2 478	2 756	0.03	...	...
Ukraine	1.2	2.0	–	4	3 030	2 899	–1.16	...	...
Uzbekistan	2.1	6.4	10	26	2 583	2 273	–1.93	...	...

TABLE A3
Agricultural production and productivity

	Crop and livestock production		Per capita food production		Cereal yields	
	(Average annual growth rate [%])				(hg/ha)	(Average annual growth rate [%])
	1983–1992	1993–2002	1983–1992	1993–2002	1998–2002	1993–2002
WORLD	**2.1**	**2.1**	**0.5**	**0.8**	**30 885**	**1.1**
DEVELOPED COUNTRIES	**0.5**	**0.0**	**–0.1**	**–0.3**	**36 602**	**1.1**
DEVELOPING COUNTRIES	**3.6**	**3.4**	**–0.2**	**0.8**	**27 867**	**1.3**
ASIA AND THE PACIFIC	**4.2**	**3.8**	**–0.6**	**0.7**	**34 106**	**1.3**
American Samoa	–2.1	0.1	...	...	...	...
Bangladesh	2.3	3.0	–0.2	1.2	32 059	2.5
Bhutan	1.6	–0.4	–0.8	–2.4	14 966	3.4
British Virgin Islands	5.3	0.0	...	...	...	...
Brunei Darussalam	–3.7	16.3	...	...	15 984	4.7
Cambodia	4.6	3.8	0.5	1.3	19 718	4.2
China, Hong Kong SAR	4.6	8.4	...	...	0	...
China, Macao SAR	8.1	5.5	...	...	...	...
China, Mainland	2.5	5.6	...	...	48 883	1.3
China, Taiwan Province of	3.4	0.3	...	...	54 804	1.5
Cocos (Keeling) Islands	1.9	2.7	...	...	...	...
Cook Islands	–13.7	–0.4	...	...	...	...
Fiji Islands	2.0	0.3	1.0	–0.8	21 119	18.8
French Polynesia	1.4	–6.9	...	...	...	...
Guam	1.3	1.9	–1.0	0.6	20 000	0.0
India	3.9	2.1	1.9	0.6	23 501	1.5
Indonesia	5.2	1.1	3.3	–0.2	39 722	0.7
Kiribati	5.3	2.0	3.7	0.8	...	...
Korea, Democratic People's Republic of	4.2	–0.1	...	...	29 228	–1.4
Korea, Republic of	2.6	–0.5	...	...	63 042	0.3
Lao People's Dem. Republic	4.2	5.7	1.5	3.9	30 264	3.0
Malaysia	4.2	2.0	3.3	1.0	30 033	0.5
Maldives	2.6	3.3	–0.5	0.5	11 600	4.0
Marshall Islands	–13.5	–10.6	...	...	...	...
Mongolia	0.4	0.6	–2.3	–0.2	6 930	–1.2
Myanmar	0.6	5.2	–1.2	3.8	31 596	1.9
Nauru	0.8	0.2	–1.4	–2.3	...	...
Nepal	4.2	3.8	2.0	1.6	21 100	2.4
New Caledonia	–9.5	0.1	...	...	36 899	2.8
Niue	–1.7	0.9	3.3	0.9	...	...
Pakistan	4.4	3.4	1.2	1.4	22 519	1.8
Papua New Guinea	0.7	2.7	...	...	41 043	4.8
Philippines	1.2	3.4	–1.1	1.7	25 369	2.7
Samoa	–4.8	3.1	–5.2	3.2	...	...
Singapore	–5.2	–7.0	–7.4	–9.4	...	...
Solomon Islands	8.6	2.1	...	...	39 872	...
Sri Lanka	0.3	2.2	–0.7	0.6	34 134	2.4

TABLE A3 *(cont.)*

	Crop and livestock production		Per capita food production		Cereal yields	
	(Average annual growth rate [%])				*(hg/ha)*	*(Average annual growth rate [%])*
	1983–1992	**1993–2002**	**1983–1992**	**1993–2002**	**1998–2002**	**1993–2002**
Thailand	3.0	1.6	0.9	0.4	26 619	1.9
Timor-Leste	6.3	–0.2	3.3	0.2	20 049	1.6
Tokelau	3.3	0.3	3.3	10.3	...	...
Tonga	–0.3	0.6	–0.6	0.3	...	...
Tuvalu	5.2	–2.5	4.2	–3.5	...	...
Vanuatu	1.2	–0.5	–1.3	–2.9	5 385	0.6
Viet Nam	4.2	5.5	1.9	3.6	40 921	3.2
Wallis and Futuna Islands	0.6	0.0	...	...	...	...
LATIN AMERICA AND THE CARIBBEAN	**2.3**	**3.2**	**0.3**	**1.3**	**28 722**	**1.8**
Antigua and Barbuda	–0.5	–1.1	...	...	16 029	–1.3
Argentina	1.2	2.8	–0.2	1.9	33 990	1.1
Bahamas	0.5	6.8	–1.4	5.2	20 886	3.0
Barbados	–1.5	1.6	–1.9	1.2	25 000	–0.8
Belize	4.7	3.9	2.2	2.0	26 482	3.2
Bermuda	0.2	–1.9	–0.7	–2.4	...	...
Bolivia	2.8	4.7	0.7	2.6	16 081	3.0
Brazil	3.5	4.2	1.7	3.0	27 751	3.0
Cayman Islands	–28.4	0.0	...	...	...	...
Chile	3.6	2.9	2.0	1.7	47 182	2.6
Colombia	2.9	1.2	0.7	0.5	32 436	3.0
Costa Rica	5.1	2.7	2.4	0.8	39 237	2.8
Cuba	–1.7	–0.5	–2.5	–0.9	25 259	6.1
Dominica	3.4	–1.6	3.7	–1.7	13 077	–0.4
Dominican Republic	–1.5	–0.8	...	...	40 728	1.1
Ecuador	3.8	3.5	1.2	1.8	20 333	1.2
El Salvador	1.7	–1.1	2.3	–1.8	21 301	3.2
Falkland Islands (Malvinas)	1.9	2.8	...	...	...	...
French Guiana	3.5	3.8	...	...	26 333	–2.0
Grenada	–0.8	0.0	–1.0	–0.3	10 000	–0.2
Guadeloupe	–0.8	1.8	–2.5	1.0	0	...
Guatemala	2.1	2.2	0.5	0.7	17 484	–0.3
Guyana	–0.3	3.8	0.1	3.4	38 622	1.2
Haiti	–0.9	0.6	–3.0	–0.8	8 975	–1.3
Honduras	1.7	2.9	–1.6	0.0	12 772	0.8
Jamaica	2.8	1.4	1.9	0.7	11 556	–2.5
Martinique	0.7	2.5	–0.4	1.9	...	...
Mexico	1.5	2.6	–0.3	1.1	27 396	0.3
Montserrat	1.7	0.4	1.7	15.0	18 750	0.0
Netherlands Antilles	4.6	–10.1	...	...	...	...
Nicaragua	–1.2	3.5	–2.3	1.9	16 628	0.3

TABLE A3 *(cont.)*

	Crop and livestock production		Per capita food production		Cereal yields	
	(Average annual growth rate [%])				*(hg/ha)*	*(Average annual growth rate [%])*
	1983–1992	**1993–2002**	**1983–1992**	**1993–2002**	**1998–2002**	**1993–2002**
Panama	0.8	1.0	–1.3	–0.5	25 456	8.6
Paraguay	4.9	2.4	2.0	0.8	20 083	1.1
Peru	0.9	6.5	–0.8	4.9	31 087	4.9
Puerto Rico	0.5	–1.3	–0.4	–2.2	18 704	7.3
Saint Kitts and Nevis	3.0	–7.0	...	...	...	...
Saint Lucia	19.7	9.1	...	...	0	...
Saint Vincent and the Grenadines	15.4	–1.7	...	...	33 333	0.0
Suriname	0.4	–2.3	–0.7	–2.6	37 899	0.1
Trinidad and Tobago	3.1	8.1	...	...	29 729	–1.6
US Virgin Islands	8.6	0.0	...	...	...	...
Uruguay	0.7	1.7	0.1	1.8	34 926	2.5
Venezuela	0.0	2.6	...	...	32 841	2.9
NEAR EAST AND NORTH AFRICA	**3.4**	**2.1**	**1.0**	**0.7**	**20 278**	**2.3**
Afghanistan	–1.3	2.8	–2.0	–0.7	12 240	7.2
Algeria	6.7	1.9	4.2	0.3	10 082	5.5
Bahrain	3.3	–0.3	–0.1	–2.5	...	...
Cyprus	2.2	2.0	0.9	0.8	17 852	12.2
Egypt	3.7	3.5	1.8	2.0	71 554	2.0
Iran, Islamic Republic of	8.5	5.7	...	...	20 039	2.7
Iraq	1.1	–0.8	–1.7	–3.0	5 788	–0.4
Jordan	8.2	4.1	3.8	1.2	16 182	5.7
Kuwait	12.6	26.2	10.3	27.6	23 063	–6.0
Lebanon	5.6	–0.6	4.5	–3.0	23 311	5.0
Libyan Arab Jamahiriya	–2.3	2.9	...	...	6 508	–1.1
Morocco	3.5	5.2	1.1	3.7	8 400	44.6
Oman	2.1	4.5	–2.3	1.4	22 808	0.9
Palestine, Occupied Territory	5.2	0.3	1.0	1.6	16 497	28.5
Qatar	11.4	4.0	5.5	2.2	35 891	1.0
Saudi Arabia	16.6	1.0	12.2	–1.7	35 533	–1.6
Syrian Arab Republic	3.6	12.6	...	...	16 120	10.3
Tunisia	7.9	2.8	5.8	1.7	13 107	3.7
Turkey	2.5	1.2	0.3	–0.2	22 315	1.2
United Arab Emirates	–8.4	7.9	...	...	5 187	–3.3
Yemen	3.7	3.3	0.1	–0.8	10 657	–0.8
SUB-SAHARAN AFRICA	**3.1**	**2.1**	**–1.0**	**0.0**	**10 792**	**1.9**
Angola	1.8	4.9	–1.0	2.2	6 226	7.2
Benin	7.2	5.7	2.6	2.6	10 670	0.7
Botswana	0.9	–0.7	–2.2	–2.3	1 630	–2.3

TABLE A3 *(cont.)*

	Crop and livestock production		Per capita food production		Cereal yields	
	(Average annual growth rate [%])				*(hg/ha)*	*(Average annual growth rate [%])*
	1983–1992	1993–2002	1983–1992	1993–2002	1998–2002	1993–2002
Burkina Faso	6.5	5.1	3.5	2.5	9 143	1.7
Burundi	3.2	–1.3	0.2	–2.0	12 898	–0.5
Cameroon	2.0	2.8	–0.7	0.6	17 329	5.7
Cape Verde	8.2	4.5	6.3	2.4	6 762	62.8
Central African Republic	–0.5	1.9	...	...	10 618	1.0
Chad	4.1	3.8	1.3	1.0	6 296	0.9
Comoros	2.9	2.5	0.0	0.0	13 262	0.3
Congo, Democratic Republic of	2.6	–5.8	...	...	7 871	0.1
Congo, Republic of	2.7	4.4	...	...	8 149	0.9
Côte d'Ivoire	6.5	–1.2	...	...	13 815	3.8
Djibouti	5.6	0.8	0.9	–1.2	16 250	0.8
Equatorial Guinea	–1.3	1.9	...	...	...	...
Eritrea	–0.7	3.1	–5.7	2.2	6 189	...
Ethiopia	1.0	4.5	2.8	1.9	11 602	2.8
Ethiopia PDR	0.9	...	–2.1	...	0	...
Gabon	2.5	1.6	–0.5	–1.2	16 334	–0.7
Gambia	–3.9	4.5	–7.7	1.7	12 153	–0.8
Ghana	7.4	5.6	4.1	3.4	12 959	3.1
Guinea	2.6	3.9	–0.8	1.5	13 707	2.6
Guinea-Bissau	1.3	2.9	...	...	10 619	–3.6
Kenya	3.3	2.5	–0.3	0.2	15 073	1.3
Lesotho	0.2	3.6	–2.7	3.6	10 596	13.3
Liberia	–2.9	5.5	–2.2	–0.8	12 461	3.6
Madagascar	1.7	1.3	–1.0	–1.2	19 535	0.5
Malawi	–0.4	5.5	–6.1	6.6	13 817	21.9
Mali	2.5	4.1	–1.0	1.0	10 635	4.2
Mauritania	1.0	1.2	–1.5	–1.5	8 165	3.8
Mauritius	0.3	–0.1	–0.6	–0.5	77 317	9.6
Mozambique	–2.1	5.3	–3.3	2.5	8 882	26.7
Namibia	1.6	0.0	–1.8	–2.1	3 292	23.5
Niger	2.8	4.1	–0.5	0.9	3622	3.9
Nigeria	7.1	3.0	3.9	0.5	11 242	–1.0
Rwanda	2.0	3.2	0.9	0.0	9 236	3.0
Réunion	4.0	1.4	2.3	–0.1	67 244	1.5
Sao Tome and Principe	0.8	6.1	...	...	22 571	1.4
Senegal	1.2	1.9	–1.4	–0.3	7 761	–0.5
Seychelles	–0.9	3.3	–2.5	2.3	...	...
Sierra Leone	0.8	–0.6	–1.8	–1.5	11 520	0.1
Somalia	–2.7	4.5	–3.4	2.1	4 813	–0.3
South Africa	0.0	2.9	–2.0	1.6	24 873	19.3
Sudan	2.7	3.0	1.0	0.9	5 387	0.8
Swaziland	1.4	0.5	–1.4	–1.4	16 426	9.0

TABLE A3 *(cont.)*

	Crop and livestock production		Per capita food production		Cereal yields	
	(Average annual growth rate [%])				*(hg/ha)*	*(Average annual growth rate [%])*
	1983–1992	**1993–2002**	**1983–1992**	**1993–2002**	**1998–2002**	**1993–2002**
Tanzania, United Republic of	0.9	–0.9	...	...	13 532	3.9
Togo	3.7	3.9	–0.4	0.8	9 957	2.6
Uganda	2.6	3.4	–0.4	0.4	15 984	1.4
Zambia	2.2	4.6	–1.1	1.8	13 922	18.3
Zimbabwe	0.7	4.3	–4.0	4.3	10 605	30.1
DEVELOPED MARKET ECONOMIES	**1.0**	**0.6**	**0.3**	**–0.2**	**48 087**	**0.7**
Australia	3.2	0.8	1.7	0.7	18 787	–1.4
Austria	–0.2	0.7	–0.6	0.4	58 125	1.9
Belgium/Luxembourg	2.2	0.5	2.0	0.2	77 958	3.1
Canada	1.2	1.4	0.0	0.4	26 830	–0.4
Denmark	0.9	1.1	0.8	0.8	60 161	3.4
Faeroe Islands	0.8	–7.2	0.4	–7.3	...	...
Finland	–0.9	0.8	–1.3	0.5	29 976	3.0
France	0.8	0.1	0.3	–0.3	72 146	1.5
Germany	–0.3	0.2	–0.6	0.0	65 593	1.8
Greece	1.3	–0.3	0.4	–0.8	35 899	0.0
Greenland	–0.5	0.1	–1.1	0.1	...	...
Iceland	–1.5	0.6	–2.5	–0.1	...	...
Ireland	2.3	0.0	2.1	–0.8	71 115	0.2
Israel	0.3	1.2	–1.2	–1.1	24 551	4.0
Italy	0.8	–0.5	0.7	–0.6	50 113	0.8
Japan	0.2	–1.0	–0.1	–1.2	60 534	1.6
Liechtenstein	2.8	–0.7	1.4	–1.6	...	...
Malta	2.1	1.2	1.2	0.6	40 015	3.6
Netherlands	1.7	–1.1	1.1	–1.6	73 247	–0.3
New Zealand	0.6	2.2	0.2	1.9	63 059	1.7
Norway	–0.8	0.0	–1.2	–0.5	38 052	3.6
Portugal	2.6	0.8	2.7	0.7	28 385	6.0
Spain	1.8	2.0	1.4	1.9	31 435	10.2
Saint Pierre and Miquelon	133.9	0.0	133.9	–1.3	...	...
Sweden	–1.8	1.2	–2.2	1.0	45 747	4.9
Switzerland	0.2	–0.7	–0.7	–1.0	64 757	1.9
United Kingdom	0.7	–0.9	0.3	–1.1	68 583	1.4
United States of America	1.5	1.2	0.4	0.3	57 446	1.2
COUNTRIES IN TRANSITION	**–0.5**	**–1.7**	**–1.0**	**–1.4**	**21 316**	**2.2**
Albania	–0.6	4.3	–2.1	5.2	28 554	3.6
Armenia	7.2	0.5	...	0.1	17 489	5.1
Azerbaijan	1.4	0.6	...	1.3	22 559	3.1
Belarus	15.1	–2.2	...	–1.9	18 868	–0.4

TABLE A3 *(cont.)*

	Crop and livestock production		Per capita food production		Cereal yields	
	(Average annual growth rate [%])				*(hg/ha)*	*(Average annual growth rate [%])*
	1983–1992	1993–2002	1983–1992	1993–2002	1998–2002	1993–2002
Bosnia and Herzegovina	...	0.2	...	–0.4	31 069	0.8
Bulgaria	–2.7	–1.6	–2.0	–0.5	29 798	5.3
Croatia	...	0.6	...	0.4	46 377	3.1
Czech Republic	...	–1.1	...	...	42 147	0.7
Czechoslovakia	–0.2	...	–0.3	...	0	...
Estonia	12.5	–5.3	...	–4.0	18 135	9.0
Georgia	5.3	–0.8	...	0.3	17 588	2.1
Hungary	–2.3	0.1	–1.9	0.5	43 439	2.5
Kazakhstan	8.3	–2.1	...	–1.4	10 341	6.5
Kyrgyzstan	17.1	2.2	...	2.0	26 973	1.7
Latvia	10.9	–6.5	...	–5.7	21 193	4.7
Lithuania	17.8	–2.9	...	–2.7	25 035	4.9
Macedonia, The Former Yugoslav Republic of	...	–1.7	...	–2.2	27 486	2.6
Moldova, Republic of	6.9	–1.6	...	–1.1	24 415	2.8
Poland	0.0	0.1	–0.4	0.0	29 714	3.6
Romania	–3.5	1.6	–3.7	2.0	26 761	6.0
Russian Federation	11.0	–2.2	...	–1.7	16 579	3.0
Serbia–Montenegro	...	–1.7	...	–2.0	37 390	6.3
Slovakia	...	–2.0	...	...	36 852	0.3
Slovenia	...	3.0	...	2.8	50 839	4.0
Tajikistan	2.9	–2.7	...	–3.0	12 788	3.9
Turkmenistan	6.7	1.1	...	2.8	21 404	9.2
USSR	–9.6	...	–10.2	...	0	...
Ukraine	11.1	–2.7	...	–2.0	23 061	1.2
Uzbekistan	6.3	0.5	...	–0.1	26 598	6.6
Yugoslavia SFR	–9.9	...	–10.3	...	0	...

TABLE A4
Population and labour force indicators (2001)

	Total population	Rural population		Agricultural population		Economically active population	Economically active population in agriculture	
	(Thousands)	*(Thousands)*	*(% of total)*	*(Thousands)*	*(% of total)*	*(Thousands)*	*(Thousands)*	*(%)*
WORLD	**6 130 564**	**3 209 953**	**52**	**2 574 870**	**42**	**2 992 057**	**1 326 504**	**44**
DEVELOPED COUNTRIES	**1 274 401**	**333 785**	**26**	**90 702**	**7**	**640 157**	**44 911**	**7**
DEVELOPING COUNTRIES	**4 856 163**	**2 876 168**	**59**	**2 484 168**	**51**	**2 351 900**	**1 281 593**	**54**
ASIA AND THE PACIFIC	**3 257 570**	**2 141 994**	**66**	**1 855 475**	**57**	**1 675 947**	**1 004 002**	**60**
American Samoa	70	33	47	24	34	28	9	32
Bangladesh	140 369	104 426	74	76 722	55	71 395	39 023	55
Bhutan	2 141	1 983	93	2 007	94	1 033	968	94
British Virgin Islands	24	9	38	6	25	11	3	27
Brunei Darussalam	335	91	27	2	1	152	1	1
Cambodia	13 441	11 089	83	9 364	70	6 601	4 599	70
China, Hong Kong SAR	6 961	10	0	28	0	3 771	15	0
China, Macao SAR	449	5	1	0	0	236	0	0
China, Mainland	1 262 609	812 003	64	849 785	67	759 651	510 092	67
China, Taiwan Province of	22 363	1 164	5	3 276	15	9 869	773	8
Cook Islands	20	8	40	7	35	8	3	38
Fiji Islands	823	410	50	325	39	331	131	40
French Polynesia	237	113	48	80	34	102	34	33
Guam	158	95	60	46	29	71	19	27
India	1 025 096	739 399	72	545 254	53	451 384	267 125	59
Indonesia	214 840	124 469	58	93 312	43	104 777	49 955	48
Kiribati	84	52	62	22	26	35	9	26
Korea, Democratic People's Republic of	22 428	8 854	39	6 589	29	11 511	3 382	29
Korea, Republic of	47 069	8 274	18	3 876	8	24 258	2 268	9
Lao People's Dem. Republic of	5 403	4 337	80	4 123	76	2 699	2 059	76
Malaysia	22 633	9 481	42	3 841	17	9 673	1 736	18
Maldives	300	216	72	78	26	127	27	21
Marshall Islands	52	18	35	14	27	21	6	29
Micronesia, Federated States of	126	90	71	33	26	52	14	27
Mongolia	2 559	1 109	43	603	24	1 324	312	24
Myanmar	48 364	34 769	72	33 806	70	26 157	18 284	70
Northern Mariana Islands	76	36	47	20	26	31	8	26
Nauru	13	0	0	3	23	5	1	20
Nepal	23 593	20 721	88	21 929	93	11 138	10 352	93
New Caledonia	220	48	22	79	36	116	42	36
Niue	2	1	50	1	50	1	0	0
Pakistan	144 971	96 574	67	73 030	50	53 737	25 033	47
Palau	20	6	30	5	25	8	2	25
Papua New Guinea	4 920	4 052	82	3 768	77	2 372	1 745	74

TABLE A4 *(cont.)*

	Total population	Rural population		Agricultural population		Economically active population	Economically active population in agriculture	
	(Thousands)	*(Thousands)*	*(% of total)*	*(Thousands)*	*(% of total)*	*(Thousands)*	*(Thousands)*	*(%)*
Philippines	77 131	31 321	41	29 883	39	32 217	12 541	39
Samoa	159	123	77	54	34	55	19	35
Singapore	4 108	0	0	6	0	2 053	3	0
Solomon Islands	463	369	80	337	73	230	167	73
Sri Lanka	19 104	14 685	77	8 788	46	8 662	3 916	45
Thailand	63 584	50 891	80	30 631	48	37 858	21 076	56
Timor-Leste	750	677	90	613	82	392	321	82
Tokelau	1	1	100	0	0	1	0	0
Tonga	99	67	68	33	33	39	13	33
Tuvalu	10	5	50	3	30	4	1	25
Vanuatu	202	157	78	73	36	88	32	36
Viet Nam	79 175	59 738	75	52 991	67	41 657	27 881	67
Wallis and Futuna Islands	15	15	100	5	33	6	2	33
LATIN AMERICA AND THE CARIBBEAN	**526 568**	**127 305**	**24**	**107 179**	**20**	**227 380**	**43 938**	**19**
Anguilla	12	0	0	3	25	5	1	20
Antigua and Barbuda	65	41	63	15	23	30	7	23
Argentina	37 488	4 374	12	3 709	10	15 335	1 462	10
Aruba	104	51	49	24	23	47	11	23
Bahamas	308	34	11	11	4	159	6	4
Barbados	268	133	50	11	4	149	6	4
Belize	231	120	52	70	30	82	25	30
Bermuda	63	0	0	1	2	33	1	3
Bolivia	8 516	3 161	37	3 638	43	3 487	1 531	44
Brazil	172 559	31 528	18	27 458	16	80 302	12 949	16
Cayman Islands	40	0	0	9	23	18	4	22
Chile	15 402	2 144	14	2 401	16	6 342	982	15
Colombia	42 803	10 489	25	8 666	20	18 655	3 706	20
Costa Rica	4 112	1 665	40	840	20	1 675	329	20
Cuba	11 237	2 758	25	1 793	16	5 592	771	14
Dominica	71	20	28	16	23	32	7	22
Dominican Republic	8 507	2 893	34	1 447	17	3 710	595	16
Ecuador	12 880	4 707	37	3 453	27	5 092	1 282	25
El Salvador	6 400	2 461	38	2 067	32	2 782	790	28
French Guiana	170	42	25	30	18	72	13	18
Grenada	94	58	62	22	23	43	10	23
Guadeloupe	431	2	0	13	3	204	6	3
Guatemala	11 687	7 020	60	5 765	49	4 293	1 952	45
Guyana	763	484	63	132	17	323	56	17
Haiti	8 270	5 263	64	5 096	62	3 582	2 210	62
Honduras	6 575	3 043	46	2 218	34	2 493	767	31
Jamaica	2 598	1 129	43	526	20	1 303	264	20

TABLE A4 *(cont.)*

	Total population	Rural population		Agricultural population		Economically active population	Economically active population in agriculture	
	(Thousands)	*(Thousands)*	*(% of total)*	*(Thousands)*	*(% of total)*	*(Thousands)*	*(Thousands)*	*(%)*
Martinique	386	18	5	15	4	189	7	4
Mexico	100 368	25 555	25	23 064	23	41 692	8 714	21
Montserrat	3	2	67	1	33	2	0	0
Netherlands Antilles	217	67	31	1	0	99	0	0
Nicaragua	5 208	2 266	44	1 046	20	2 056	396	19
Panama	2 899	1 260	43	654	23	1 231	244	20
Paraguay	5 636	2 442	43	2 250	40	2 142	726	34
Peru	26 093	7 009	27	7 689	29	9 991	2 968	30
Puerto Rico	3 952	965	24	110	3	1 506	32	2
Saint Kitts and Nevis	38	25	66	9	24	17	4	24
Saint Lucia	149	93	62	34	23	66	15	23
Saint Vincent and the Grenadines	114	50	44	26	23	52	12	23
Suriname	419	106	25	79	19	162	30	19
Trinidad and Tobago	1 300	332	26	111	9	587	50	9
Turks and Caicos Islands	17	9	53	4	24	8	2	25
US Virgin Islands	122	65	53	27	22	56	13	23
Uruguay	3 361	264	8	372	11	1 518	190	13
Venezuela	24 632	3 157	13	2 253	9	10 166	792	8
NEAR EAST AND NORTH AFRICA	**405 003**	**170 979**	**42**	**119 514**	**30**	**152 281**	**49 849**	**33**
Afghanistan	22 474	17 411	77	14 976	67	9 153	6 099	67
Algeria	30 841	13 034	42	7 307	24	10 857	2 613	24
Bahrain	652	49	8	7	1	307	3	1
Cyprus	790	236	30	65	8	390	32	8
Egypt	69 080	39 601	57	24 805	36	26 566	8 665	33
Iran, Islamic Republic of	71 369	25 133	35	18 465	26	25 062	6 515	26
Iraq	23 584	7 690	33	2 272	10	6 568	633	10
Jordan	5 051	1 075	21	561	11	1 624	180	11
Kuwait	1 971	77	4	21	1	845	9	1
Lebanon	3 556	353	10	123	3	1 295	45	3
Libyan Arab Jamahiriya	5 408	651	12	303	6	1 846	103	6
Morocco	30 430	13 345	44	10 877	36	12 093	4 271	35
Oman	2 622	620	24	917	35	749	262	35
Qatar	575	41	7	7	1	317	4	1
Saudi Arabia	21 028	2 799	13	1 928	9	6 338	581	9
Syrian Arab Republic	16 610	8 008	48	4 535	27	5 375	1 468	27
Tunisia	9 562	3 232	34	2 319	24	3 913	949	24
Turkey	67 632	22 946	34	20 365	30	31 851	14 485	45
United Arab Emirates	2 654	339	13	125	5	1 386	65	5
Yemen	19 114	14 339	75	9 536	50	5 746	2 867	50

TABLE A4 *(cont.)*

	Total population	Rural population		Agricultural population		Economically active population	Economically active population in agriculture	
	(Thousands)	*(Thousands)*	*(% of total)*	*(Thousands)*	*(% of total)*	*(Thousands)*	*(Thousands)*	*(%)*
SUB-SAHARAN AFRICA	**667 022**	**435 890**	**65**	**402 000**	**60**	**296 292**	**183 804**	**62**
Angola	13 527	8 816	65	9 681	72	6 104	4 368	72
Benin	6 446	3 669	57	3 417	53	2 920	1 548	53
Botswana	1 554	791	51	688	44	680	301	44
Burkina Faso	11 856	9 841	83	10 937	92	5 609	5 174	92
Burundi	6 502	5 862	90	5 865	90	3 433	3 097	90
Cameroon	15 203	7 643	50	7 821	51	6 261	3 647	58
Cape Verde	437	159	36	98	22	179	40	22
Central African Republic	3 782	2 211	58	2 716	72	1 780	1 278	72
Chad	8 135	6 171	76	6 043	74	3 722	2 765	74
Comoros	727	481	66	532	73	341	250	73
Congo, Democratic Republic of the	52 522	36 308	69	32 948	63	21 286	13 353	63
Congo, Republic of the	3 110	1 054	34	1 241	40	1 268	506	40
Côte d'Ivoire	16 349	9 147	56	7 858	48	6 689	3 215	48
Djibouti	644	102	16	505	78	315	248	79
Equatorial Guinea	470	238	51	329	70	194	136	70
Eritrea	3 816	3 066	80	2 947	77	1 906	1 472	77
Ethiopia	64 459	54 222	84	52 842	82	28 416	23 294	82
Gabon	1 262	223	18	461	37	566	207	37
Gambia	1 337	919	69	1 052	79	687	540	79
Ghana	19 734	12 553	64	11 041	56	9 771	5 534	57
Guinea	8 274	5 977	72	6 907	83	4 104	3 426	83
Guinea-Bissau	1 227	829	68	1 013	83	560	462	83
Kenya	31 293	20 542	66	23 467	75	16 188	12 140	75
Lesotho	2 057	1 468	71	774	38	874	329	38
Liberia	3 108	1 705	55	2 083	67	1 237	829	67
Madagascar	16 437	11 488	70	12 133	74	7 861	5 803	74
Malawi	11 572	9 807	85	8 912	77	5 564	4 587	82
Mali	11 677	8 068	69	9 391	80	5 695	4 580	80
Mauritania	2 747	1 126	41	1 444	53	1 213	638	53
Mauritius	1 171	684	58	131	11	513	59	12
Mozambique	18 644	12 471	67	14 128	76	9 766	7 844	80
Namibia	1 788	1 226	69	862	48	708	287	41
Niger	11 227	8 859	79	9 827	88	5 170	4 525	88
Nigeria	116 929	64 384	55	37 880	32	46 450	15 048	32
Réunion	7 949	7 582	95	7 168	90	4 321	3 897	90
Rwanda	732	204	28	22	3	303	9	3
Sao Tome and Principe	140	73	52	89	64	59	38	64
Senegal	9 662	5 006	52	7 091	73	4 294	3 151	73
Seychelles	81	29	36	64	79	39	31	79
Sierra Leone	4 587	2 841	62	2 827	62	1 697	1 046	62

TABLE A4 *(cont.)*

	Total population	Rural population		Agricultural population		Economically active population	Economically active population in agriculture	
	(Thousands)	*(Thousands)*	*(% of total)*	*(Thousands)*	*(% of total)*	*(Thousands)*	*(Thousands)*	*(%)*
Somalia	9 157	6 593	72	6 475	71	3 906	2 762	71
South Africa	43 792	18 521	42	6 035	14	18 247	1 690	9
Saint Helena	6	2	33	3	50	3	1	33
Sudan	31 809	20 017	63	19 136	60	12 557	7 554	60
Swaziland	938	688	73	309	33	347	114	33
Tanzania, United Republic of	35 965	23 980	67	27 944	78	18 556	14 845	80
Togo	4 657	3 084	66	2 752	59	1 972	1 166	59
Uganda	24 023	20 527	85	18 851	78	11 714	9 326	80
Zambia	10 649	6 417	60	7 304	69	4 498	3 085	69
Zimbabwe	12 852	8 216	64	7 956	62	5 749	3 559	62
DEVELOPED MARKET ECONOMIES	**863 444**	**181 277**	**21**	**29 316**	**3**	**430 006**	**14 224**	**3**
Andorra	90	7	8	8	9	41	4	10
Australia	19 338	1 687	9	871	5	9 872	444	4
Austria	8 075	2 631	33	397	5	3 728	183	5
Belgium	10 264	267	3	181	2	4 223	74	2
Canada	31 015	6 535	21	766	2	16 690	380	2
Denmark	5 333	795	15	194	4	2 926	106	4
Faeroe Islands	47	29	62	2	4	24	1	4
Finland	5 178	2 170	42	295	6	2 592	137	5
France	59 453	14 549	24	1 896	3	26 893	857	3
Germany	82 007	10 053	12	1 969	2	40 288	967	2
Gibraltar	27	0	0	2	7	12	1	8
Greece	10 623	4 217	40	1 381	13	4 643	752	16
Greenland	56	10	18	1	2	29	1	3
Iceland	281	21	7	23	8	159	13	8
Ireland	3 841	1 568	41	377	10	1 629	160	10
Israel	6 172	506	8	160	3	2 662	69	3
Italy	57 503	18 945	33	2 911	5	25 383	1 285	5
Japan	127 335	26 877	21	4 646	4	68 318	2 607	4
Liechtenstein	33	26	79	1	3	16	0	0
Luxembourg	442	36	8	9	2	186	4	2
Malta	392	35	9	6	2	149	2	1
Monaco	34	0	0	1	3	16	0	0
Netherlands	15 930	1 657	10	521	3	7 370	241	3
New Zealand	3 808	537	14	330	9	1 901	169	9
Norway	4 488	1 122	25	221	5	2 323	103	4
Portugal	10 033	3 437	34	1 390	14	5 109	630	12
San Marino	27	3	11	2	7	12	1	8
Spain	39 921	8 846	22	2 780	7	17 611	1 234	7
Saint Pierre and Miquelon	7	1	14	0	0	4	0	0

TABLE A4 *(cont.)*

	Total population	Rural population		Agricultural population		Economically active population	Economically active population in agriculture	
	(Thousands)	*(Thousands)*	*(% of total)*	*(Thousands)*	*(% of total)*	*(Thousands)*	*(Thousands)*	*(%)*
Sweden	8 833	1 474	17	302	3	4 792	146	3
Switzerland	7 170	2 347	33	457	6	3 806	156	4
United Kingdom	59 762	6 350	11	1 054	2	29 964	529	2
United States of America	285 926	64 539	23	6 162	2	146 635	2 968	2
COUNTRIES IN TRANSITION	**410 957**	**152 508**	**37**	**61 386**	**15**	**210 151**	**30 687**	**15**
Albania	3 145	1 784	57	1 496	48	1 573	748	48
Armenia	3 788	1 241	33	469	12	1 951	242	12
Azerbaijan	8 096	3 906	48	2 123	26	3 707	972	26
Belarus	10 147	3 095	31	1 283	13	5 427	686	13
Bosnia and Herzegovina	4 067	2 318	57	194	5	1 904	91	5
Bulgaria	7 867	2 566	33	559	7	4 066	269	7
Croatia	4 655	1 949	42	370	8	2 195	174	8
Czech Republic	10 260	2 613	25	815	8	5 749	457	8
Estonia	1 377	421	31	152	11	763	84	11
Georgia	5 239	2 279	44	1 015	19	2 655	514	19
Hungary	9 917	3 491	35	1 152	12	4 744	490	10
Kazakhstan	16 095	7 110	44	3 110	19	8 012	1 386	17
Kyrgyzstan	4 986	3 284	66	1 251	25	2 220	557	25
Latvia	2 406	982	41	280	12	1 330	155	12
Lithuania	3 689	1 158	31	526	14	1 933	228	12
Macedonia, The Former Yugoslav Republic of	2 044	832	41	249	12	947	115	12
Moldova, Republic of	4 285	2 519	59	940	22	2 192	481	22
Poland	38 577	14 462	37	7 133	18	20 048	4 243	21
Romania	22 388	10 031	45	2 956	13	10 726	1 547	14
Russian Federation	144 664	39 208	27	14 779	10	78 069	7 975	10
Serbia–Montenegro	10 538	5 096	48	2 015	19	5 068	969	19
Slovakia	5 403	2 295	42	475	9	2 977	262	9
Slovenia	1 985	1 011	51	34	2	1 017	18	2
Tajikistan	6 135	4 437	72	2 031	33	2 467	817	33
Turkmenistan	4 835	2 665	55	1 594	33	2 111	696	33
Ukraine	49 112	15 720	32	7 571	15	25 214	3 520	14
Uzbekistan	25 257	16 035	63	6 814	27	11 086	2 991	27

TABLE A5
Land use

	Total land area (Thousand ha)	Forest and wood area (Thousand ha)	Agricultural area (Thousand ha)	Agricultural area per capita (ha/person)	Arable land (% of agricultural area)	Permanent crops (% of agricultural area)	Permanent pasture (% of agricultural area)	Irrigated area (% of arable + permanent crops area)	Fertilizer consumption (kg/ha arable land)
	2001	2000	2001	2001	2001	2001	2001	2001	2001
WORLD	**13 041 038**	**3 868 796**	**5 016 729**	**0.82**	**27.9**	**2.6**	**69.5**	**17.8**	**98.3**
DEVELOPED COUNTRIES	**5 382 812**	**1 720 221**	**1 743 778**	**1.36**	**34.3**	**1.3**	**64.4**	**10.7**	**84.0**
DEVELOPING COUNTRIES	**7 658 226**	**2 148 575**	**3 272 951**	**0.67**	**24.5**	**3.3**	**72.2**	**22.7**	**109.0**
ASIA AND THE PACIFIC	**2 014 355**	**511 796**	**1 029 003**	**0.32**	**39.8**	**5.2**	**55.0**	**33.2**	**163.2**
American Samoa	20	12	5	0.07	**40.0**	60.0	0.0	0.0	0.0
Bangladesh	13 017	1 334	9 085	0.06	89.0	4.4	6.6	52.1	167.6
Bhutan	4 700	3 016	580	0.27	25.0	3.4	71.6	24.2	0.0
British Virgin Islands	15	3	9	0.38	33.3	11.1	55.6	0.0	0.0
Brunei Darussalam	527	442	13	0.04	23.1	30.8	46.2	14.3	0.0
Cambodia	17 652	9 335	5 307	0.39	69.7	2.0	28.3	7.1	0.0
China, Hong Kong SAR	99	...	7	0.00	71.4	14.3	14.3	33.3	0.0
China, Macao SAR	2	...	...	0.00	...	...	...	...	...
China, Mainland	929 100	163 480	554 420	0.44	25.8	2.1	72.1	35.1	244.8
China, Taiwan Province of	3 541	...	849	0.04	73.0	27.0	0.0	68.3	681.9
Cocos (Keeling) Islands	1	...	...	...	...	...	...	...	...
Cook Islands	23	22	7	0.35	57.1	42.9	0.0	0.0	0.0
Fiji Islands	1 827	815	460	0.56	43.5	18.5	38.0	1.1	50.0
French Polynesia	366	105	43	0.18	7.0	46.5	46.5	4.3	400.0
Guam	55	21	22	0.14	22.7	40.9	36.4	0.0	0.0
India	297 319	64 113	180 810	0.18	89.5	4.5	6.0	32.3	107.6
Indonesia	181 157	104 986	44 777	0.21	45.8	29.3	25.0	14.3	123.1
Kiribati	73	28	39	0.46	5.1	94.9	0.0	0.0	0.0
Korea, Democratic People's Republic of	12 041	8 210	2 850	0.13	87.7	10.5	1.8	52.1	114.8
Korea, Republic of	9 873	6 248	1 943	0.04	87.3	9.9	2.8	60.6	422.6
Lao People's Dem. Rep. of	23 080	12 561	1 836	0.34	47.8	4.4	47.8	18.3	14.0
Malaysia	32 855	19 292	7 870	0.35	22.9	73.5	3.6	4.8	628.2
Maldives	30	1	10	0.03	40.0	50.0	10.0	0.0	0.0
Marshall Islands	18	...	14	0.27	21.4	50.0	28.6	0.0	0.0
Micronesia, Federated States of	70	15	47	0.37	8.5	68.1	23.4	0.0	0.0
Mongolia	156 650	10 645	130 500	51.00	0.9	0.0	99.1	7.0	2.7
Myanmar	65 755	34 419	10 939	0.23	91.3	5.8	2.9	18.7	16.4

TABLE A5 *(cont.)*

	Total land area *(Thousand ha)*	Forest and wood area *(Thousand ha)*	Agricultural area *(Thousand ha)*	Agricultural area per capita *(ha/person)*	Arable land *(% of agricultural area)*	Permanent crops *(% of agricultural area)*	Permanent pasture *(% of agricultural area)*	Irrigated area *(% of arable + permanent crops area)*	Fertilizer consumption *(kg/ha arable land)*
	2001	2000	2001	2001	2001	2001	2001	2001	2001
Northern Mariana Islands	46	14	13	0.17	46.2	15.4	38.5	0.0	0.0
Nauru	2	...	...	0.00	...	...	...	...	...
Nepal	14 300	3 900	4 949	0.21	62.6	1.9	35.5	35.6	22.7
New Caledonia	1 828	372	229	1.04	3.1	2.6	94.3	0.0	128.6
Niue	26	6	8	4.00	50.0	37.5	12.5	0.0	0.0
Norfolk Island	4	...	1	...	0.0	0.0	100.0	...	...
Pakistan	77 088	2 361	27 160	0.19	79.1	2.5	18.4	80.4	136.0
Palau	46	35	9	0.45	44.4	22.2	33.3	0.0	0.0
Papua New Guinea	45 286	30 601	1 035	0.21	20.3	62.8	16.9	0.0	56.2
Philippines	29 817	5 789	11 930	0.15	47.4	41.9	10.7	14.6	138.3
Samoa	283	105	131	0.82	45.8	52.7	1.5	0.0	81.7
Singapore	61	2	1	0.00	100.0	0.0	0.0	0.0	2353.0
Solomon Islands	2 799	2 536	114	0.25	15.8	49.1	35.1	0.0	0.0
Sri Lanka	6 463	1 940	2 351	0.12	38.1	43.2	18.7	31.2	261.7
Thailand	51 089	14 762	19 100	0.30	78.5	17.3	4.2	26.9	114.5
Timor-Leste	1 487	...	230	0.31	30.4	4.3	65.2	0.0	0.0
Tokelau	1	...	...	0.00	...	...	...	...	...
Tonga	72	4	52	0.53	32.7	59.6	7.7	0.0	0.0
Tuvalu	3	...	...	0.00	...	...	...	...	...
Vanuatu	1 219	447	162	0.80	18.5	55.6	25.9	0.0	0.0
Viet Nam	32 549	9 819	9 080	0.11	71.6	21.3	7.1	35.6	307.6
Wallis and Futuna Islands	20	...	6	0.40	16.7	83.3	0.0	0.0	0.0
LATIN AMERICA AND THE CARIBBEAN	**2 017 772**	**964 355**	**784 197**	**1.49**	**19.0**	**2.6**	**78.4**	**11.0**	**84.8**
Antigua and Barbuda	44	9	14	0.22	57.1	14.3	28.6	0.0	0.0
Argentina	273 669	34 648	177 000	4.72	19.0	0.7	80.2	4.5	25.5
Aruba	19	...	2	0.02	100.0	0.0	0.0	0.0	0.0
Bahamas	1 001	842	14	0.05	57.1	28.6	14.3	8.3	100.0
Barbados	43	2	19	0.07	84.2	5.3	10.5	5.9	187.5
Belize	2 280	1 348	154	0.67	42.2	25.3	32.5	2.9	72.3
Bermuda	5	...	1	0.02	100.0	0.0	0.0	0.0	100.0
Bolivia	108 438	53 068	36 931	4.34	7.9	0.5	91.6	4.3	4.2
Brazil	845 651	543 905	263 465	1.53	22.3	2.9	74.8	4.4	115.1
Cayman Islands	26	13	3	0.08	33.3	0.0	66.7	0.0	0.0
Chile	74 880	15 536	15 235	0.99	13.0	2.1	84.9	82.6	242.7
Colombia	103 870	49 601	46 049	1.08	5.5	3.8	90.8	21.2	254.5
Costa Rica	5 106	1 968	2 865	0.70	7.9	10.5	81.7	20.6	568.7
Cuba	10 982	2 348	6 665	0.59	54.5	12.5	33.0	19.5	55.3
Dominica	75	46	22	0.31	22.7	68.2	9.1	0.0	600.0

TABLE A5 *(cont.)*

	Total land area (Thousand ha)	Forest and wood area (Thousand ha)	Agricultural area (Thousand ha)	Agricultural area per capita (ha/person)	Arable land (% of agricultural area)	Permanent crops (% of agricultural area)	Permanent pasture (% of agricultural area)	Irrigated area (% of arable + permanent crops area)	Fertilizer consumption (kg/ha arable land)
	2001	2000	2001	2001	2001	2001	2001	2001	2001
Dominican Republic	4 838	1 376	3 696	0.43	29.7	13.5	56.8	17.2	89.5
Ecuador	27 684	10 557	8 075	0.63	20.1	16.9	63.0	29.0	142.3
El Salvador	2 072	121	1 704	0.27	38.7	14.7	46.6	4.9	110.9
Falkland Islands (Malvinas)	1 217	...	1 130	565.00	0.0	0.0	100.0	...	...
French Guiana	8 815	7 926	23	0.14	52.2	17.4	30.4	12.5	100.0
Grenada	34	5	13	0.14	15.4	76.9	7.7	0.0	0.0
Guadeloupe	169	82	48	0.11	39.6	12.5	47.9	24.0	1015.8
Guatemala	10 843	2 850	4 507	0.39	30.2	12.1	57.7	6.8	134.5
Guyana	19 685	16 879	1 740	2.28	27.6	1.7	70.7	29.4	27.1
Haiti	2 756	88	1 590	0.19	49.1	20.1	30.8	6.8	17.9
Honduras	11 189	5 383	2 936	0.45	36.4	12.3	51.4	5.6	141.9
Jamaica	1 083	325	513	0.20	33.9	21.4	44.6	8.8	67.2
Martinique	106	47	33	0.09	33.3	30.3	36.4	33.3	1609.1
Mexico	190 869	55 205	107 300	1.07	23.1	2.3	74.6	23.2	75.4
Montserrat	10	3	3	1.00	66.7	0.0	33.3	0.0	0.0
Netherlands Antilles	80	1	8	0.04	100.0	0.0	0.0	0.0	0.0
Nicaragua	12 140	3 278	6 986	1.34	27.7	3.4	68.9	4.4	11.7
Panama	7 443	2 876	2 230	0.77	24.6	6.6	68.8	5.0	53.3
Paraguay	39 730	23 372	24 810	4.40	12.2	0.4	87.5	2.2	22.1
Peru	128 000	65 215	31 310	1.20	11.8	1.6	86.6	28.4	81.3
Puerto Rico	887	229	294	0.07	11.9	16.7	71.4	47.6	0.0
Saint Kitts and Nevis	36	4	10	0.26	70.0	10.0	20.0	0.0	242.9
Saint Lucia	61	9	20	0.13	20.0	70.0	10.0	16.7	1325.0
Saint Vincent and the Grenadines	39	6	16	0.14	43.8	43.8	12.5	7.1	557.1
Suriname	15 600	14 113	88	0.21	64.8	11.4	23.9	76.1	98.2
Trinidad and Tobago	513	259	133	0.10	56.4	35.3	8.3	3.3	144.9
Turks and Caicos Islands	43	...	1	0.06	100.0	0.0	0.0	0.0	0.0
Uruguay	17 502	1 292	14 883	4.43	8.7	0.3	91.0	13.5	92.0
US Virgin Islands	34	14	10	0.08	40.0	10.0	50.0	0.0	150.0
Venezuela	88 205	49 506	21 648	0.88	12.0	3.7	84.3	16.9	115.5
NEAR EAST AND NORTH AFRICA	**1 263 233**	**28 820**	**454 982**	**1.12**	**18.9**	**2.6**	**78.5**	**28.5**	**70.9**
Afghanistan	65 209	1 351	38 054	1.69	20.8	0.4	78.8	29.6	2.3
Algeria	238 174	2 145	40 052	1.30	19.1	1.5	79.4	6.8	13.7
Bahrain	71	...	10	0.02	20.0	40.0	40.0	66.7	150.0
Cyprus	924	172	117	0.15	61.5	35.0	3.4	35.4	315.5
Egypt	99 545	72	3 338	0.05	85.6	14.4	0.0	100.0	457.4
Iran, Islamic Republic of	163 620	7 299	60 548	0.85	23.6	3.8	72.7	45.3	92.5

TABLE A5 *(cont.)*

	Total land area (Thousand ha)	Forest and wood area (Thousand ha)	Agricultural area (Thousand ha)	Agricultural area per capita (ha/person)	Arable land (% of agricultural area)	Permanent crops (% of agricultural area)	Permanent pasture (% of agricultural area)	Irrigated area (% of arable + permanent crops area)	Fertilizer consumption (kg/ha arable land)
	2001	2000	2001	2001	2001	2001	2001	2001	2001
Iraq	43 737	799	10 090	0.43	57.0	3.4	39.6	57.9	57.6
Jordan	8 893	86	1 142	0.23	20.8	14.3	65.0	20.0	94.3
Kuwait	1 782	5	151	0.08	8.6	1.3	90.1	86.7	80.5
Lebanon	1 023	36	329	0.09	51.7	43.5	4.9	33.2	321.1
Libyan Arab Jamahiriya	175 954	358	15 450	2.86	11.7	2.2	86.1	21.9	30.9
Morocco	44 630	3 025	30 720	1.01	28.5	3.2	68.4	13.8	41.2
Oman	30 950	1	1 081	0.41	3.5	4.0	92.5	76.5	157.7
Palestine, Occupied Territory	618	...	358	...	30.4	33.0	41.9	10.6	0.0
Qatar	1 100	1	71	0.12	25.4	4.2	70.4	61.9	50.0
Saudi Arabia	214 969	1 504	173 794	8.26	2.1	0.1	97.8	42.7	106.6
Syrian Arab Republic	18 378	461	13 723	0.83	33.8	5.9	60.3	23.2	60.0
Tunisia	15 536	510	8 999	0.94	30.8	23.7	45.4	7.8	39.2
Turkey	76 963	10 225	38 733	0.57	61.5	6.6	32.0	17.1	70.1
United Arab Emirates	8 360	321	543	0.20	9.2	34.6	56.2	31.9	700.0
Yemen	52 797	449	17 660	0.92	8.3	0.7	91.0	31.3	11.1
SUB-SAHARAN AFRICA	**2 362 866**	**643 604**	**1 004 769**	**1.51**	**15.8**	**2.2**	**82.1**	**3.7**	**12.6**
Angola	124 670	69 756	57 300	4.24	5.2	0.5	94.2	2.3	0.0
Benin	11 062	2 650	2 815	0.44	71.0	9.4	19.5	0.5	15.6
Botswana	56 673	12 427	25 973	16.71	1.4	0.0	98.6	0.3	12.4
Burkina Faso	27 360	7 089	10 000	0.84	39.5	0.5	60.0	0.6	8.2
Burundi	2 568	94	2 195	0.34	41.0	16.4	42.6	5.9	3.9
Cameroon	46 540	23 858	9 160	0.60	65.1	13.1	21.8	0.5	8.8
Cape Verde	403	85	66	0.15	59.1	3.0	37.9	7.3	2.6
Central African Republic	62 298	22 907	5 145	1.36	37.5	1.7	60.7	0.0	0.3
Chad	125 920	12 692	48 630	5.98	7.4	0.1	92.5	0.6	4.9
Comoros	223	8	147	0.20	54.4	35.4	10.2	0.0	3.8
Congo, Democratic Republic of the	226 705	135 207	22 880	0.44	29.3	5.2	65.6	0.1	0.2
Congo, Republic of the	34 150	22 060	10 220	3.29	1.7	0.4	97.8	0.5	28.6
Côte d'Ivoire	31 800	7 117	20 500	1.25	15.1	21.5	63.4	1.0	20.2
Djibouti	2 318	6	1 301	2.02	0.1	0.0	99.9	100.0	0.0
Equatorial Guinea	2 805	1 752	334	0.71	38.9	29.9	31.1	0.0	0.0
Eritrea	10 100	1 585	7 470	1.96	6.7	0.0	93.3	4.2	20.0
Ethiopia	100 000	4 593	31 462	0.49	34.0	2.4	63.6	1.7	12.6
Gabon	25 767	21 826	5 160	4.09	6.3	3.3	90.4	3.0	0.9
Gambia	1 000	481	714	0.53	35.0	0.7	64.3	0.8	3.2
Ghana	22 754	6 335	14 250	0.72	26.0	15.4	58.6	0.2	2.8

TABLE A5 *(cont.)*

	Total land area (Thousand ha)	Forest and wood area (Thousand ha)	Agricultural area (Thousand ha)	Agricultural area per capita (ha/person)	Arable land (% of agricultural area)	Permanent crops (% of agricultural area)	Permanent pasture (% of agricultural area)	Irrigated area (% of arable + permanent crops area)	Fertilizer consumption (kg/ha arable land)
	2001	2000	2001	2001	2001	2001	2001	2001	2001
Guinea	24 572	6 929	12 225	1.48	7.3	5.2	87.5	6.2	3.6
Guinea-Bissau	2 812	2 187	1 628	1.33	18.4	15.2	66.3	3.1	8.0
Kenya	56 914	17 096	26 460	0.85	17.4	2.1	80.5	1.7	31.4
Lesotho	3 035	14	2 334	1.13	14.1	0.2	85.7	0.3	34.4
Liberia	9 632	3 481	2 600	0.84	14.6	8.5	76.9	0.5	0.0
Madagascar	58 154	11 727	27 550	1.68	10.7	2.2	87.1	30.7	2.3
Malawi	9 408	2 562	4 190	0.36	52.5	3.3	44.2	1.3	10.3
Mali	122 019	13 186	34 700	2.97	13.4	0.1	86.5	2.9	9.0
Mauritania	102 522	317	39 750	14.47	1.2	0.0	98.7	9.8	4.1
Mauritius	203	16	113	0.10	88.5	5.3	6.2	20.8	372.0
Mozambique	78 409	30 601	48 235	2.59	8.3	0.5	91.2	2.5	6.2
Namibia	82 329	8 040	38 820	21.71	2.1	0.0	97.9	0.9	0.4
Niger	126 670	1 328	16 500	1.47	27.2	0.1	72.7	1.5	1.1
Nigeria	91 077	13 517	70 400	0.60	40.5	3.8	55.7	0.7	7.8
Réunion	250	71	49	0.07	69.4	6.1	24.5	32.4	147.1
Rwanda	2 467	307	1 850	0.23	54.1	16.2	29.7	0.4	0.3
Saint Helena	31	2	12	2.00	33.3	0.0	66.7	0.0	0.0
Sao Tome and Principe	96	27	54	0.39	11.1	87.0	1.9	18.9	0.0
Senegal	19 253	6 205	8 150	0.84	30.2	0.5	69.3	2.8	16.2
Seychelles	45	30	7	0.09	14.3	85.7	0.0	0.0	20.0
Sierra Leone	7 162	1 055	2 764	0.60	18.1	2.3	79.6	5.3	0.6
Somalia	62 734	7 515	44 071	4.81	2.4	0.1	97.6	18.7	0.5
South Africa	122 104	8 917	99 640	2.28	14.8	1.0	84.2	9.5	50.1
Sudan	237 600	61 627	133 833	4.21	12.1	0.3	87.6	11.7	4.9
Swaziland	1 720	522	1 390	1.48	12.8	0.9	86.3	36.8	39.3
Tanzania, United Republic of	88 359	38 811	39 950	1.11	10.0	2.4	87.6	3.4	5.6
Togo	5 439	510	3 630	0.78	69.1	3.3	27.5	0.7	7.6
Uganda	19 710	4 190	12 312	0.51	41.4	17.1	41.5	0.1	1.1
Zambia	74 339	31 246	35 280	3.31	14.9	0.1	85.0	0.9	6.9
Zimbabwe	38 685	19 040	20 550	1.60	15.7	0.6	83.7	3.5	47.3
DEVELOPED MARKET ECONOMIES	**3 070 589**	**783 052**	**1 110 147**	**1.27**	**31.7**	**1.4**	**66.9**	**11.3**	**121.3**
Andorra	45	...	26	0.29	3.8	0.0	96.2	0.0	0.0
Australia	768 230	154 539	455 500	23.55	11.0	0.1	88.9	4.7	49.0
Austria	8 273	3 886	3 390	0.42	41.3	2.1	56.6	0.3	162.1
Belgium/ Luxembourg	3 282	728	1 544	0.14	54.5	1.6	43.9	4.6	343.2
Canada	922 097	244 571	74 880	2.41	61.1	0.2	38.7	1.6	52.2
Denmark	4 243	455	2 676	0.50	85.7	0.3	14.1	19.4	138.3
Faeroe Islands	140	...	3	0.06	100.0	0.0	0.0	0.0	0.0

TABLE A5 *(cont.)*

	Total land area (Thousand ha)	Forest and wood area (Thousand ha)	Agricultural area (Thousand ha)	Agricultural area per capita (ha/person)	Arable land (% of agricultural area)	Permanent crops (% of agricultural area)	Permanent pasture (% of agricultural area)	Irrigated area (% of arable + permanent crops area)	Fertilizer consumption (kg/ha arable land)
	2001	2000	2001	2001	2001	2001	2001	2001	2001
Finland	30 459	21 935	2 219	0.43	98.7	0.4	0.9	2.9	135.6
France	55 010	15 341	29 631	0.50	62.3	3.8	33.9	13.3	226.5
Germany	34 895	10 740	17 033	0.21	69.4	1.2	29.4	4.0	221.1
Gibraltar	1	...	...	0.00	...	...	...	...	...
Greece	12 890	3 599	8 502	0.80	32.0	13.3	54.7	37.1	154.4
Greenland	41 045	...	235	4.20	0.0	0.0	100.0	...	...
Iceland	10 025	31	2 281	8.12	0.3	0.0	99.7	0.0	3 028.6
Ireland	6 889	659	4 399	1.15	23.8	0.0	76.2	0.0	547.3
Israel	2 062	132	566	0.09	59.7	15.2	25.1	45.8	263.3
Italy	29 411	10 003	15 355	0.27	53.2	18.3	28.5	24.6	205.7
Japan	36 450	24 081	5 199	0.04	85.5	6.7	7.8	54.8	304.6
Liechtenstein	16	7	9	0.27	44.4	0.0	55.6	0.0	0.0
Malta	32	...	10	0.03	90.0	10.0	0.0	20.0	77.8
Monaco	...	...	...	0.00	...	...	...	...	...
Netherlands	3 388	375	1 931	0.12	46.9	1.7	51.4	60.2	451.9
New Zealand	26 799	7 946	17 235	4.53	8.7	10.9	80.4	8.5	592.8
Norway	30 683	8 868	1 042	0.23	84.5	0.0	15.5	14.4	217.0
Portugal	9 150	3 666	4 142	0.41	48.0	17.3	34.7	24.0	114.6
Saint Pierre and Miquelon	23	...	3	0.43	100.0	0.0	0.0	0.0	0.0
San Marino	6	...	1	0.04	100.0	0.0	0.0	0.0	390.0
Spain	49 944	14 370	29 398	0.74	44.3	16.8	38.9	20.4	167.7
Sweden	41 162	27 134	3 144	0.36	85.7	0.1	14.2	4.3	106.5
Switzerland	3 955	1 199	1 580	0.22	26.1	1.5	72.4	5.7	221.9
United Kingdom	24 088	2 794	16 954	0.28	33.3	0.3	66.4	1.9	337.8
United States of America	915 896	225 993	411 259	1.44	42.6	0.5	56.9	12.7	111.9
COUNTRIES IN TRANSITION	**2 312 223**	**937 169**	**633 631**	**1.54**	**38.9**	**1.1**	**60.0**	**9.8**	**30.7**
Albania	2 740	991	1 139	0.36	50.7	10.6	38.6	48.6	32.4
Armenia	2 820	351	1 360	0.36	36.4	4.8	58.8	51.3	10.1
Azerbaijan	8 660	1 094	4 535	0.56	37.5	5.2	57.3	75.2	7.0
Belarus	20 748	9 402	9 250	0.91	66.3	1.3	32.4	2.1	127.2
Bosnia and Herzegovina	5 073	2 273	1 850	0.45	37.3	8.1	64.9	0.4	47.2
Bulgaria	11 055	3 690	6 251	0.79	70.8	3.4	25.8	17.3	35.4
Croatia	5 592	1 783	3 149	0.68	46.3	4.0	49.6	0.3	147.5
Czech Republic	7 728	2 632	4 278	0.42	71.9	5.5	22.6	0.7	128.3
Estonia	4 227	2 060	890	0.65	76.2	2.1	21.7	0.6	62.3
Georgia	6 949	2 988	3 003	0.57	26.5	8.9	64.6	44.1	52.8
Hungary	9 211	1 840	5 865	0.59	78.7	3.2	18.1	4.8	70.0
Kazakhstan	269 970	12 148	206 769	12.85	10.4	0.1	89.5	10.8	2.3
Kyrgyzstan	19 180	1 003	10 758	2.16	13.0	0.6	86.4	73.1	5.0
Latvia	6 205	2 923	2 480	1.03	74.2	1.2	24.6	1.1	34.8

TABLE A5 *(cont.)*

	Total land area (Thousand ha)	Forest and wood area (Thousand ha)	Agricultural area (Thousand ha)	Agricultural area per capita (ha/person)	Arable land (% of agricultural area)	Permanent crops (% of agricultural area)	Permanent pasture (% of agricultural area)	Irrigated area (% of arable + permanent crops area)	Fertilizer consumption (kg/ha arable land)
	2001	2000	2001	2001	2001	2001	2001	2001	2001
Lithuania	6 480	1 994	3 487	0.95	84.0	1.7	14.3	0.2	55.3
Macedonia, The Former Yugoslav Republic of	2 543	906	1 242	0.61	45.6	3.7	50.7	9.0	53.5
Moldova, Republic of	3 291	325	2 559	0.60	71.1	13.9	15.0	14.1	2.8
Poland	30 435	9 047	18 392	0.48	76.0	1.8	22.2	0.7	111.4
Romania	23 034	6 448	14 852	0.66	63.3	3.5	33.2	31.1	34.8
Russian Federation	1 688 850	851 392	216 861	1.50	57.1	0.9	42.0	3.7	12.9
Serbia–Montenegro	10 200	2 887	5 592	0.53	60.8	5.8	33.3	0.8	78.2
Slovakia	4 808	2 177	2 450	0.45	59.2	5.1	35.7	11.6	82.6
Slovenia	2 012	1 107	510	0.26	33.9	5.9	60.2	1.5	418.9
Tajikistan	14 060	400	4 560	0.74	20.4	2.9	76.8	67.8	13.0
Turkmenistan	46 993	3 755	32 515	6.72	5.4	0.2	94.4	99.2	66.9
Ukraine	57 935	9 584	41 404	0.84	78.6	2.2	19.1	7.2	14.6
Uzbekistan	41 424	1 969	27 630	1.09	16.2	1.2	82.5	88.6	154.6

TABLE A6
Trade indicators (average 1999–2001)

	Agricultural exports (Million US$)	Agricultural imports (Million US$)	Agricultural exports as share of total exports (%)	Agricultural imports as share of total imports (%)	Net food imports (Thousand US$)	Agricultural exports relative to agricultural GDP (%)
WORLD	**414 219**	**437 650**	**6.9**	**7.1**	**15 934 841**	**33.4**
DEVELOPED COUNTRIES	**289 662**	**306 612**	**6.9**	**6.9**	**13 803 974**	**64.1**
DEVELOPING COUNTRIES	**124 558**	**131 039**	**6.9**	**7.7**	**2 130 867**	**18.3**
ASIA AND THE PACIFIC	**51 331**	**60 643**	**4.4**	**5.6**	**2 003 351**	**12.1**
American Samoa	5	21	1.5	4.0	12 868	...
Bangladesh	100	1 613	1.8	20.5	811 629	0.9
Bhutan	17	20	14.0	8.4	–637	11.5
British Virgin Islands	0	8	0.3	5.5	2 844	...
Brunei Darussalam	1	186	0.0	14.0	136 107	...
Cambodia	31	353	8.2	48.3	65 552	2.5
China, Hong Kong SAR	3 991	8 397	2.1	4.3	3 375 162	3044.3
China, Macao SAR	40	274	1.7	12.3	112 098	...
China, Mainland	11 605	9 148	5.0	4.3	–5 454 607	6.7
China, Taiwan Province of	1 010	5 720	0.8	4.9	2 345 745	...
Cook Islands	0	11	2.6	11.4	9 092	...
Fiji Islands	164	111	28.6	13.2	–54 902	63.6
French Polynesia	8	277	2.2	18.8	237 743	4.2
Guam	0	55	0.1	11.4	36 900	...
India	4 958	3 634	11.8	7.3	–2 701 894	4.7
Indonesia	4 817	4 292	8.4	14.3	934 484	18.7
Kiribati	2	13	38.4	34.6	9 258	...
Korea, Democratic People's Republic of	26	379	2.7	29.1	278 675	...
Korea, Republic of	1 609	7 963	1.0	5.7	3 806 767	7.9
Lao People's Dem. Republic	32	75	10.2	13.9	9 124	3.8
Malaysia	6 151	3 851	6.9	5.3	1 381 494	77.2
Maldives	0	71	0.1	18.0	56 571	...
Marshall Islands	1	0	...	...	–18	11.9
Micronesia, Federated States of	4	15	16.6	23.7	11 330	...
Mongolia	93	76	26.1	14.4	30 679	29.2
Myanmar	362	342	22.1	13.9	–177 903	...
Nauru	...	1	...	6.7	912	...
Nepal	60	244	9.5	17.2	71 417	3.0
New Caledonia	3	127	0.4	8.8	88 984	...
Niue	0	1	77.7	8.8	178	...
Norfolk Island	1	3	32.2	11.1	1 329	...
Pakistan	1 093	1 868	12.6	18.4	–23 013	7.6
Papua New Guinea	324	183	16.6	18.3	5 462	35.8
Philippines	1 447	2 569	4.0	7.9	1 229 989	12.1
Samoa	5	16	34.6	14.1	12 494	14.9

TABLE A6 *(cont.)*

	Agricultural exports (Million US$)	Agricultural imports (Million US$)	Agricultural exports as share of total exports (%)	Agricultural imports as share of total imports (%)	Net food imports (Thousand US$)	Agricultural exports relative to agricultural GDP (%)
Singapore	2 829	4 070	2.3	3.5	1 238 978	2433.3
Solomon Islands	41	24	54.2	26.4	16 235	...
Sri Lanka	968	753	19.6	11.9	–223 728	34.1
Thailand	7 285	2 643	11.6	4.6	–4 224 055	58.8
Timor-Leste	0	1	...	...	1 233	...
Tonga	11	21	59.4	28.3	8 993	20.3
Tuvalu	0	1	0.0	21.2	1 140	...
Vanuatu	17	18	65.2	19.4	6 496	44.2
Viet Nam	2 219	1 193	16.5	8.5	–1 485 349	29.4
Wallis and Futuna Islands	0	1	7.1	4.5	1 493	...
LATIN AMERICA AND THE CARIBBEAN	**50 087**	**28 148**	**19.2**	**9.2**	**–15 959 752**	**43.0**
Antigua and Barbuda	0	32	0.5	4.8	25 342	1.9
Argentina	10 883	1 292	42.9	5.5	–6 446 597	85.5
Aruba	13	67	0.7	2.9	45 790	...
Bahamas	45	334	1.7	20.0	249 130	...
Barbados	70	156	26.5	14.1	65 871	55.1
Belize	125	53	65.4	12.5	–80 292	91.9
Bermuda	0	93	0.0	2.5	66 752	...
Bolivia	402	233	33.0	13.1	–77 511	36.7
Brazil	14 215	3 865	26.5	6.9	–7 339 680	39.5
Cayman Islands	...	59	...	11.8	40 475	...
Chile	2 933	1 181	16.9	7.1	–1 109 132	54.8
Colombia	2 890	1 431	23.5	12.3	–1 171 932	27.9
Costa Rica	1 686	451	29.8	7.3	–1 138 468	119.0
Cuba	683	720	41.3	15.3	46 524	...
Dominica	22	30	42.3	23.7	–123	55.1
Dominican Republic	539	555	63.4	9.5	168 736	24.6
Ecuador	1 469	392	31.6	9.9	–929 201	88.7
El Salvador	520	662	18.7	14.0	32 630	40.1
Falkland Islands (Malvinas)	2	0	...	...	0	...
Grenada	22	34	35.4	14.9	9 334	81.7
Guatemala	1 449	677	56.7	13.7	–717 225	32.9
Guyana	191	55	37.6	6.8	–136 063	99.5
Haiti	27	362	8.6	35.4	266 593	...
Honduras	488	415	38.2	14.6	–73 931	64.4
Jamaica	262	409	17.4	13.5	143 407	51.6
Mexico	7 413	9 714	9.2	9.3	1 207 431	33.6
Montserrat	0	5	1.6	24.6	3 231	...
Netherlands Antilles	15	138	0.9	6.5	94 062	...
Nicaragua	365	290	62.1	16.1	–90 686	...
Panama	313	396	38.4	12.1	60 576	45.5

TABLE A6 *(cont.)*

	Agricultural exports (Million US$)	Agricultural imports (Million US$)	Agricultural exports as share of total exports (%)	Agricultural imports as share of total imports (%)	Net food imports (Thousand US$)	Agricultural exports relative to agricultural GDP (%)
Paraguay	674	426	69.2	15.0	–36 236	42.8
Peru	681	1 002	10.2	12.9	186 027	16.4
Saint Kitts and Nevis	11	20	26.6	11.8	4 396	127.7
Saint Lucia	34	73	57.5	19.3	34 435	80.0
Saint Vincent and the Grenadines	34	32	73.7	19.6	–5 713	115.2
Suriname	65	110	17.2	23.1	11 706	80.4
Trinidad and Tobago	220	316	6.2	10.0	128 624	160.8
Uruguay	981	389	44.6	11.8	–561 344	80.3
Venezuela	344	1 678	1.4	10.4	1 063 309	6.1
NEAR EAST AND NORTH AFRICA	**11 235**	**31 908**	**3.7**	**13.6**	**16 320 023**	**11.4**
Afghanistan	55	225	47.4	38.3	145 238	...
Algeria	28	2 570	0.2	25.0	2 267 586	0.6
Bahrain	29	388	0.6	9.1	291 901	...
Cyprus	429	676	43.9	17.6	184 070	...
Egypt	571	3 447	10.7	22.0	2 348 862	3.8
Iran, Islamic Republic of	1 032	2 736	4.3	18.0	1 241 800	5.2
Iraq	8	1 577	0.1	50.6	1 311 372	...
Jordan	303	834	15.2	19.3	495 608	186.2
Kuwait	47	1 180	0.3	15.7	1 012 899	...
Lebanon	149	1 162	19.7	17.7	800 237	7.8
Libyan Arab Jamahiriya	41	796	0.5	18.1	616 486	...
Morocco	760	1 618	10.6	14.6	549 618	15.0
Oman	418	1 138	4.2	22.0	430 137	...
Palestine, Occupied Territory	94	590	24.0	23.0	412 139	...
Qatar	9	300	0.1	10.5	251 428	...
Saudi Arabia	402	4 816	0.6	16.2	3 819 394	...
Syrian Arab Republic	1 494	1 664	33.6	41.6	361 070	36.5
Tunisia	487	784	8.0	8.8	380 164	19.7
Turkey	3 975	2 769	14.0	6.1	–2 099 958	17.0
United Arab Emirates	895	2 382	1.2	5.0	1 275 501	...
Yemen	71	812	2.4	36.8	632 845	5.3
SUB-SAHARAN AFRICA	**11 905**	**10 340**	**13.6**	**12.7**	**–232 755**	**21.9**
Angola	3	383	0.1	15.3	227 648	0.5
Benin	176	127	45.5	18.9	89 393	20.6
Botswana	117	376	4.4	17.3	205 818	87.0
Burkina Faso	118	184	56.4	31.6	110 133	12.6

TABLE A6 *(cont.)*

	Agricultural exports (Million US$)	Agricultural imports (Million US$)	Agricultural exports as share of total exports (%)	Agricultural imports as share of total imports (%)	Net food imports (Thousand US$)	Agricultural exports relative to agricultural GDP (%)
Burundi	38	19	78.2	14.1	–20 062	11.8
Cameroon	456	240	26.4	17.5	–108 141	12.1
Cape Verde	0	80	2.4	31.9	59 951	0.4
Central African Republic	23	32	11.0	21.7	12 952	4.7
Chad	96	47	51.1	11.7	–19 757	16.8
Comoros	6	18	38.1	31.2	9 494	6.7
Congo, Democratic Republic of the	36	179	8.1	36.7	118 803	1.4
Congo, Republic of the	20	122	1.0	20.8	78 851	11.1
Côte d'Ivoire	2 027	617	49.1	15.1	–1 163 584	77.5
Djibouti	3	124	20.5	77.2	48 145	19.6
Equatorial Guinea	8	12	1.9	43.7	578	7.0
Eritrea	2	44	8.5	8.6	38 739	1.8
Ethiopia	319	207	62.8	14.3	–45 341	10.5
Gabon	8	141	0.3	16.6	100 418	2.5
Gambia	12	76	32.3	39.5	62 629	9.4
Ghana	464	363	28.2	12.2	–146 871	21.7
Guinea	10	153	1.5	17.2	108 630	1.3
Guinea-Bissau	65	35	95.3	48.2	–35 895	53.0
Kenya	986	464	52.5	13.8	–481 954	51.3
Lesotho	7	158	3.1	21.6	126 895	5.4
Liberia	71	71	14.2	17.8	50 864	...
Madagascar	105	92	22.4	14.0	–22 929	9.6
Malawi	442	55	96.6	10.1	–57 403	78.3
Mali	222	122	37.5	15.1	18 863	22.8
Mauritania	34	181	9.6	51.0	100 680	17.3
Mauritius	308	282	19.6	13.6	–80 033	116.0
Mozambique	49	218	12.5	17.3	128 812	5.6
Namibia	162	199	13.8	15.0	59 996	48.0
Niger	72	130	27.0	34.9	24 023	9.4
Nigeria	393	1 369	2.3	14.3	810 921	3.6
Rwanda	41	71	65.2	31.0	13 017	5.4
Sao Tome and Principe	4	10	31.5	20.4	2 080	44.2
Senegal	138	469	14.3	28.2	341 898	16.7
Seychelles	1	49	0.8	11.5	34 227	7.6
Sierra Leone	8	133	33.3	42.4	108 631	2.5
Somalia	59	75	44.3	24.5	7 839	...
South Africa	2 218	1 337	7.8	4.9	–720 989	61.4
Saint Helena	...	3	...	35.3	2 224	...
Sudan	344	317	27.6	20.8	74 068	7.7

TABLE A6 *(cont.)*

	Agricultural exports (Million US$)	Agricultural imports (Million US$)	Agricultural exports as share of total exports (%)	Agricultural imports as share of total imports (%)	Net food imports (Thousand US$)	Agricultural exports relative to agricultural GDP (%)
Swaziland	307	197	36.4	20.6	–142 415	192.5
Tanzania, United Republic of	501	330	78.0	20.6	–102 260	13.3
Togo	89	56	27.0	12.1	6 285	17.4
Uganda	279	146	56.9	10.2	–127 113	14.0
Zambia	118	90	11.5	13.8	–4 797	17.4
Zimbabwe	940	135	43.3	6.7	–136 713	80.0
DEVELOPED MARKET ECONOMIES	**268 446**	**276 466**	**6.9**	**6.7**	**7 197 142**	**74.5**
Australia	15 255	2 978	26.3	4.8	–8 637 468	117.2
Austria	3 526	4 550	9.4	6.3	906 708	89.8
Belgium	11 451	9 692	9.3	8.4	–2 196 410	381.2
Canada	15 880	11 443	6.2	5.1	–3 353 346	...
Denmark	9 023	4 424	17.6	9.7	–4 225 597	237.2
Faeroe Islands	12	63	2.4	13.2	44 467	...
Finland	1 025	1 911	2.3	5.8	735 856	26.1
France	33 735	23 896	10.4	7.4	–5 381 690	95.4
Germany	23 781	34 620	4.3	7.1	7 206 117	111.1
Greece	2 669	3 311	24.9	11.3	1 034 042	35.0
Greenland	2	61	0.7	16.9	45 211	...
Iceland	30	186	1.5	7.6	120 779	...
Ireland	6 428	3 408	8.4	6.9	–2 737 946	212.8
Israel	1 019	1 839	3.6	5.5	644 526	...
Italy	15 737	21 512	6.6	9.3	3 665 513	54.1
Japan	1 899	35 334	0.5	10.3	23 729 602	2.5
Luxembourg	330	667	5.3	8.5	204 431	160.3
Malta	50	259	2.4	8.7	175 318	...
Netherlands	30 016	17 772	13.2	8.5	–7 350 170	329.9
New Zealand	5 980	1 115	48.0	8.4	–4 184 616	...
Norway	427	1 873	0.8	5.6	1 029 836	15.3
Portugal	1 443	4 015	5.9	10.2	2 198 608	39.7
Spain	14 179	11 208	12.9	7.8	–3 517 018	72.4
Saint Pierre and Miquelon	0	1	0.5	1.5	212	...
Sweden	1 861	4 067	2.3	6.0	1 766 723	51.3
Switzerland	2 140	4 827	2.6	5.9	1 464 504	...
United Kingdom	15 256	27 054	5.5	8.1	11 579 711	111.2
United States of America	55 293	44 380	7.5	3.8	–7 770 761	38.2
COUNTRIES IN TRANSITION	**15 310**	**24 732**	**5.7**	**9.8**	**7 502 668**	**24.0**
Albania	19	268	6.8	22.6	199 894	1.0
Armenia	33	335	10.9	38.7	282 221	6.7

TABLE A6 *(cont.)*

	Agricultural exports (Million US$)	Agricultural imports (Million US$)	Agricultural exports as share of total exports (%)	Agricultural imports as share of total imports (%)	Net food imports (Thousand US$)	Agricultural exports relative to agricultural GDP (%)
Azerbaijan	73	216	5.2	18.0	164 178	8.5
Belarus	534	912	7.7	11.8	163 798	37.9
Bosnia and Herzegovina	43	456	...	...	318 602	6.9
Bulgaria	537	354	11.8	5.6	–60 036	31.7
Croatia	394	701	8.8	8.8	308 511	25.3
Czech Republic	1 242	1 856	4.4	6.1	459 019	58.6
Estonia	274	574	7.6	12.1	177 574	92.9
Georgia	73	211	24.8	33.0	162 186	11.6
Hungary	2 276	1 025	8.2	3.3	–1 156 540	...
Kazakhstan	551	437	7.3	8.9	–134 466	32.5
Kyrgyzstan	106	80	22.2	14.7	20 102	22.0
Latvia	160	678	8.6	21.2	349 055	57.2
Lithuania	452	474	12.0	8.6	–66 253	57.9
Macedonia, The Former Yugoslav Republic of	210	245	13.5	17.8	125 045	58.0
Moldova, Republic of	320	94	63.8	11.9	–75 924	100.5
Poland	2 558	3 166	8.1	6.6	92 519	47.8
Romania	433	1 005	4.4	7.7	448 662	9.2
Russian Federation	935	7 952	1.0	22.9	5 200 734	6.0
Serbia–Montenegro	293	355	17.5	9.4	20 304	...
Slovakia	443	889	3.9	6.9	291 505	54.8
Slovenia	306	773	3.4	7.6	328 167	48.0
Tajikistan	102	132	14.4	19.6	94 914	36.9
Turkmenistan	130	173	7.4	10.1	141 242	10.9
Ukraine	1 847	954	13.4	6.9	–609 118	40.2
Uzbekistan	969	418	29.8	13.6	256 775	23.3

TABLE A7
Economic indicators

	Poverty headcount, national	GNP per capita	GDP	GDP per capita	GDP per capita, PPP	Agriculture, value added		Agriculture, value added per worker	
	(% of population)	*(Current US$)*	*(Annual % growth)*	*(Annual % growth)*	*(Current interna-tional $)*	*(% of GDP)*	*(Annual % growth)*	*(Constant 1995 US$)*	*(Annual % growth)*
	Latest year	**2001**	**1990–2001**	**1990–2001**	**2001**	**2001**	**1990–2001**	**2001**	**1990–2001**
WORLD	...	**5 232**	**2.6**	**3.2**	**7 600**	**6.2**	**2.2**	**791**	**2.4**
DEVELOPED COUNTRIES	...	**19 766**	**2.2**	**0.5**	**21 468**	**2.6**	**1.2**	**7 794**	**2.5**
DEVELOPING COUNTRIES	...	**1 274**	**4.6**	**3.9**	**3 842**	**11.9**	**3.0**	**600**	**2.4**
ASIA AND THE PACIFIC	...	**928**	**6.4**	**5.3**	**3 532**	**13.4**	**3.0**	**459**	**2.7**
Bangladesh	33.7	380	5.0	3.1	1 613	23.3	3.8	322	2.7
Bhutan	...	560	6.6	3.5	...	35.4	3.6	159	1.6
Brunei Darussalam	...	...	2.2	–0.7	...	...	2.6	...	9.2
Cambodia	36.1	280	5.1	2.3	1 591	36.9	2.0	363	–0.7
China, Hong Kong SAR	...	25 780	4.0	2.5	25 393	0.1	...	...	...
China, Macao SAR	...	14 380	3.0	1.3	18 974	...	...	...	...
China, Mainland	4.6	890	9.1	8.2	4 135	15.2	4.0	342	3.6
Fiji Islands	...	2 140	2.7	1.7	5 105	...	2.2	...	0.6
French Polynesia	...	...	2.4	0.6	...	...	...	...	...
India	28.6	470	5.6	3.7	2 493	25.0	3.0	407	1.6
Indonesia	27.1	680	4.5	3.0	3 020	17.0	2.0	749	0.8
Kiribati	...	830	2.3	0.0	...	...	3.3	...	2.9
Korea, Republic of	...	9 490	6.1	5.2	15 528	4.3	1.8	14 743	6.1
Lao People's Dem. Rep.	38.6	300	6.3	3.7	1 641	50.9	5.0	624	2.6
Malaysia	15.5	3 400	6.3	4.0	8 725	8.5	0.5	7 074	1.7
Maldives	...	2 120	5.8	3.3	...	...	2.6	2 172	3.5
Marshall Islands	...	2 270	–0.2	–1.9	...	...	...	...	...
Micronesia, Federated States of	...	1 950	1.7	–0.5	...	...	...	...	...
Mongolia	36.3	410	0.1	–1.2	1 572	31.5	2.1	1 455	2.1
Myanmar	...	...	...	5.5	...	...	...	...	...
Nepal	42.0	250	5.0	2.5	1 328	39.1	3.0	204	0.8
New Caledonia	...	...	1.8	–0.6	...	...	...	...	...
Pakistan	32.6	420	3.8	1.3	1 916	25.0	3.8	699	2.1
Palau	...	6 780	1.3	–0.8	...	3.9	...	...	...
Papua New Guinea	37.5	580	3.6	0.9	2 238	26.4	3.4	793	1.3
Philippines	36.8	1 030	3.0	0.7	3 919	15.1	1.9	1 462	0.7
Samoa	...	1 440	4.8	3.8	5 345	...	1.6	1 800	3.1
Singapore	...	21 100	6.5	3.8	22 456	0.1	–3.7	41 626	4.1

TABLE A7 *(cont.)*

	Poverty headcount, national	GNP per capita	GDP	GDP per capita	GDP per capita, PPP	Agriculture, value added		Agriculture, value added per worker	
	(% of population)	*(Current US$)*	*(Annual % growth)*	*(Annual % growth)*	*(Current interna-tional $)*	*(% of GDP)*	*(Annual % growth)*	*(Constant 1995 US$)*	*(Annual % growth)*
	Latest year	**2001**	**1990–2001**	**1990–2001**	**2001**	**2001**	**1990–2001**	**2001**	**1990–2001**
Solomon Islands	...	610	0.6	–2.7	1 614	...	...	...	...
Sri Lanka	25.0	870	4.6	3.4	3 234	19.5	2.1	717	0.8
Thailand	13.1	1 960	4.6	3.8	6 452	8.5	1.1	854	0.5
Timor-Leste	...	520	...	2.3	...	...	...	...	...
Tonga	...	1 490	2.4	1.9	6 272	...	2.9	3 100	4.5
Vanuatu	...	1 110	2.4	–0.5	2 871	...	6.0	...	4.8
Viet Nam	50.9	410	7.3	5.5	2 103	23.6	3.9	258	2.4
LATIN AMERICA AND THE CARIBBEAN	**...**	**3 750**	**2.9**	**1.3**	**7 498**	**7.6**	**2.5**	**3 675**	**2.6**
Antigua and Barbuda	...	9 150	3.0	2.4	10 319	4.0	1.9	2 645	3.2
Argentina	...	6 950	3.2	1.9	11 544	4.8	3.4	10 375	3.5
Bahamas	...	...	1.9	0.0	...	...	...	...	...
Barbados	...	9 750	1.5	1.0	16 024	5.5	0.2	17 491	3.4
Belize	...	2 940	5.1	2.6	5 786	22.7	7.3	6 179	4.7
Bermuda	...	...	1.3	...	...	...	...	...	...
Bolivia	62.7	950	3.5	1.2	2 338	15.7	2.9	747	0.8
Brazil	17.4	3 060	2.1	0.6	7 571	9.2	3.0	5 103	4.4
Chile	17.0	4 600	5.7	4.4	9 354	8.8	3.4	6 412	2.6
Colombia	17.7	1 890	2.6	0.7	6 050	13.0	0.1	3 657	–0.2
Costa Rica	22.0	3 970	4.7	2.4	8 543	9.0	3.7	5 322	2.9
Cuba	...	...	...	3.9	...	...	...	...	...
Dominica	...	3 280	1.4	1.5	5 331	17.5	–1.1	4 368	0.9
Dominican Republic	28.6	2 230	5.0	3.0	5 998	11.4	3.3	3 393	4.2
Ecuador	35.0	...	8.8	6.4	...	9.0	3.1	...	...
El Salvador	48.3	2 040	4.2	2.2	4 614	9.5	1.5	1 656	0.4
Grenada	...	3 610	3.3	2.4	6 851	8.2	–1.3	2 221	–0.6
Guatemala	57.9	1 690	3.9	1.2	3 894	22.3	2.8	2 104	0.7
Guyana	43.2	840	3.1	2.6	4 109	31.3	4.5	4 267	4.5
Haiti	...	480	–0.4	–2.5	1 611	...	...	...	...
Honduras	53.0	910	3.0	0.2	2 508	13.7	2.1	1 007	1.2
Jamaica	18.7	2 800	0.9	0.2	3 754	6.4	2.3	1 535	3.0
Mexico	...	5 560	3.4	1.7	8 738	4.3	1.9	1 832	1.7
Nicaragua	47.9	...	2.5	–0.3	...	...	4.3	...	3.9
Panama	37.3	3 920	4.8	3.1	6 146	7.0	2.7	3 308	2.4
Paraguay	21.8	1 380	2.1	–0.3	4 643	21.4	1.9	3 324	0.1
Peru	49.0	1 990	3.1	1.2	4 699	8.5	4.3	1 843	2.7
Puerto Rico	...	10 950	4.2	3.4	24 268	0.7	...	...	...
Saint Kitts and Nevis	...	6 630	3.9	3.3	11 483	2.9	0.9	2 742	2.3
Saint Lucia	...	3 950	3.5	2.2	5 350	6.6	–1.5	1 945	–3.6

TABLE A7 *(cont.)*

	Poverty headcount, national	GNP per capita	GDP	GDP per capita	GDP per capita, PPP	Agriculture, value added		Agriculture, value added per worker	
	(% of population)	*(Current US$)*	*(Annual % growth)*	*(Annual % growth)*	*(Current international $)*	*(% of GDP)*	*(Annual % growth)*	*(Constant 1995 US$)*	*(Annual % growth)*
	Latest year	**2001**	**1990–2001**	**1990–2001**	**2001**	**2001**	**1990–2001**	**2001**	**1990–2001**
Saint Vincent and the Grenadines	...	2 770	2.3	1.5	5 356	10.3	2.6	2 505	1.3
Suriname	...	1 810	2.7	2.0	...	11.3	3.5	2 241	2.5
Trinidad and Tobago	21.0	5 950	3.3	2.4	8 914	1.6	4.7	3 198	4.8
Uruguay	...	6 000	2.2	1.5	12 801	6.4	1.4	8 050	1.4
Venezuela	31.3	4 730	2.5	0.2	5 763	5.0	1.3	5 499	2.0
NEAR EAST AND NORTH AFRICA	**...**	**2 276**	**3.6**	**1.3**	**5 284**	**14.9**	**4.0**	**2 008**	**2.1**
Algeria	22.6	1 660	1.8	–0.2	5 328	9.8	4.8	2 013	1.1
Bahrain	...	11 130	4.8	2.5	16 593	...	...	...	...
Cyprus	...	12 320	4.4	3.4	17 725	...	...	...	...
Egypt	16.7	1 530	4.5	2.4	3 600	16.8	3.7	1 405	2.9
Iran, Islamic Republic of	...	1 690	4.7	3.1	6 094	18.6	4.4	3 791	3.3
Iraq	...	...	...	–42.6	...	...	...	...	...
Jordan	11.7	1 750	4.6	0.5	3 957	2.1	5.6	0	–9.9
Kuwait	...	18 270	5.2	1.4	16 328	...	...	...	...
Lebanon	...	4 000	7.1	6.1	4 217	12.0	2.2	30 832	5.8
Morocco	19.0	1 190	3.1	1.1	3 628	15.8	11.2	1 624	4.8
Oman	...	7 720	4.7	1.4	13 247	...	...	...	...
Palestine, Occupied Territory	...	...	2.0	...	...	...	–6.0	...	...
Saudi Arabia	...	8 460	2.6	–0.3	11 516	...	...	...	...
Syrian Arab Republic	...	1 040	4.8	2.0	3 332	22.5	6.5	2 669	4.1
Tunisia	7.6	2 070	5.0	3.4	6 501	11.6	5.5	3 088	3.9
Turkey	...	2 420	3.2	1.2	5 790	13.8	1.3	1 796	0.3
United Arab Emirates	...	...	3.8	-1.5	...	...	–6.1	...	...
Yemen	41.8	460	5.1	1.4	779	14.6	4.8	392	1.8
SUB-SAHARAN AFRICA	**...**	**482**	**2.4**	**0.0**	**1 744**	**17.1**	**3.0**	**360**	**1.1**
Angola	...	500	1.8	–1.3	1 815	8.0	2.3	147	–0.5
Benin	33.0	380	4.7	1.8	998	35.5	5.3	627	3.8
Botswana	...	3 100	5.7	2.9	7 954	2.4	–0.5	580	–2.3
Burkina Faso	45.3	220	4.3	1.8	976	38.2	3.9	185	1.8
Burundi	36.2	100	–0.7	–3.0	602	50.0	0.3	152	–0.9
Cameroon	...	580	1.4	–1.0	1 688	42.7	4.8	1 242	3.3
Cape Verde	...	1 320	5.4	2.8	4 657	11.0	4.2	2 646	2.8
Central African Republic	...	260	1.6	–0.7	1 155	55.4	3.6	511	2.5
Chad	64.0	200	3.0	–0.1	928	38.6	5.1	213	2.5

TABLE A7 *(cont.)*

	Poverty headcount, national	GNP per capita	GDP	GDP per capita	GDP per capita, PPP	Agriculture, value added		Agriculture, value added per worker	
	(% of population)	*(Current US$)*	*(Annual % growth)*	*(Annual % growth)*	*(Current interna-tional $)*	*(% of GDP)*	*(Annual % growth)*	*(Constant 1995 US$)*	*(Annual % growth)*
	Latest year	**2001**	**1990–2001**	**1990–2001**	**2001**	**2001**	**1990–2001**	**2001**	**1990–2001**
Comoros	...	380	1.4	–1.2	1 601	40.9	3.7	509	0.6
Congo, Democratic Rep. of the	...	80	–5.6	–8.1	629	56.3	0.6	204	–1.7
Congo, Rep. of the	...	650	1.8	–1.2	991	5.9	1.5	499	0.4
Côte d'Ivoire	36.8	640	2.3	–0.8	1 557	23.5	3.3	1 085	2.2
Djibouti	45.1	890	–0.8	–3.8	2 018	...	0.7	...	–1.1
Equatorial Guinea	...	700	22.1	16.1	23 086	8.5	6.7	953	4.1
Eritrea	53.0	160	5.8	3.0	888	18.7	9.2	80	5.4
Ethiopia	44.2	100	4.4	2.6	701	52.3	3.4	150	1.1
Gabon	...	3 160	2.7	–0.2	6 066	7.6	–0.1	2 157	0.8
Gambia	64.0	320	3.8	0.3	1 761	39.6	6.6	326	2.6
Ghana	31.4	290	4.2	1.7	1 985	35.9	3.0	574	0.4
Guinea	40.0	420	3.9	1.3	1 977	24.4	3.8	274	1.5
Guinea-Bissau	48.7	160	2.7	–0.2	860	56.2	3.9	323	1.8
Kenya	42.0	350	1.9	–0.7	996	19.0	1.0	212	–1.8
Lesotho	49.2	530	4.1	2.2	2 131	16.3	1.4	540	–0.4
Liberia	...	140	5.8	4.0	...	...	12.9	...	6.4
Madagascar	71.3	260	2.5	–0.5	848	29.8	2.0	156	–0.2
Malawi	65.3	160	3.6	1.4	582	34.0	8.7	116	5.8
Mali	...	230	3.6	1.0	824	37.8	2.2	265	0.2
Mauritania	46.3	360	3.8	0.7	1 727	20.9	4.0	492	1.7
Mauritius	10.6	3 850	5.4	4.2	10 090	6.3	1.7	6 015	3.2
Mozambique	69.4	210	6.8	4.0	...	23.2	4.3	139	1.5
Namibia	...	1 960	4.1	1.5	6 274	11.3	5.2	1 672	4.5
Niger	63.0	180	2.2	–1.2	772	40.6	3.8	208	0.4
Nigeria	34.1	290	3.1	0.3	871	34.6	3.5	742	3.2
Rwanda	51.2	240	3.9	0.5	1 143	40.5	5.4	259	2.3
Sao Tome and Principe	...	280	2.0	–0.5	...	20.0	3.9	396	3.2
Senegal	33.4	480	3.9	1.1	1 528	17.9	3.4	354	1.1
Seychelles	...	6 530	1.7	0.1	...	2.9	0.6	749	–0.9
Sierra Leone	68.0	130	–2.5	–4.8	480	50.1	–5.6	360	–5.4
Somalia	...	...	...	–8.1	...	...	...	...	...
South Africa	...	2 840	1.8	–0.1	9 916	3.2	1.6	3 987	1.7
Sudan	...	340	5.2	2.7	1 735	38.9	...	...	...
Swaziland	40.0	1 300	3.4	0.4	4 405	16.8	1.2	1 933	0.2
Tanzania, United Rep. of	41.6	...	3.6	0.8	532	44.8	3.4	190	0.9
Togo	32.3	270	1.7	–1.2	1 438	39.4	3.3	528	1.2
Uganda	55.0	260	6.3	3.2	1 291	36.4	4.0	350	1.8
Zambia	72.9	320	1.2	–1.4	790	22.1	6.1	190	2.5
Zimbabwe	34.9	...	1.4	–1.0	2 322	17.6	3.8	331	2.1

TABLE A7 *(cont.)*

	Poverty headcount, national	GNP per capita	GDP	GDP per capita	GDP per capita, PPP	Agriculture, value added		Agriculture, value added per worker	
	(% of population)	*(Current US$)*	*(Annual % growth)*	*(Annual % growth)*	*(Current interna-tional $)*	*(% of GDP)*	*(Annual % growth)*	*(Constant 1995 US$)*	*(Annual % growth)*
	Latest year	**2001**	**1990–2001**	**1990–2001**	**2001**	**2001**	**1990–2001**	**2001**	**1990–2001**
DEVELOPED MARKET ECONOMIES	**...**	**28 095**	**2.3**	**1.7**	**28 363**	**2.1**	**1.4**	**31 833**	**4.4**
Australia	...	19 930	3.4	2.1	26 864	...	3.2	...	3.1
Austria	...	23 940	2.4	1.9	28 150	2.3	3.3	33 117	6.8
Belgium	...	23 850	2.2	1.9	26 412	1.5	2.1	15 800	0.2
Canada	...	21 930	2.7	1.5	27 883	...	1.1	...	3.8
Denmark	...	30 600	2.1	1.7	29 386	2.8	2.1	61 056	5.8
Finland	...	23 780	2.2	1.6	25 333	3.5	1.0	42 240	4.9
France	...	22 730	2.0	1.5	25 749	2.9	1.8	60 468	6.1
Germany	...	23 560	1.7	1.4	26 146	1.3	1.6	34 591	6.3
Greece	...	11 430	2.4	1.9	17 406	...	0.6	...	2.5
Iceland	...	28 910	2.8	1.7	29 715	...	–1.3	48 455	–0.2
Ireland	...	22 850	7.8	6.5	32 397	...	...	...	...
Israel	...	...	5.2	2.3	...	...	...	...	...
Italy	...	19 390	1.7	1.4	25 181	2.8	1.2	27 572	5.7
Japan	...	35 610	1.6	1.3	25 672	...	–2.9	...	2.1
Luxembourg	...	39 840	5.2	3.9	56 022	...	3.9	...	...
Malta	...	9 200	4.4	3.7	16 817	...	...	...	...
Netherlands	...	24 330	2.9	2.2	27 228	...	3.0	...	5.3
New Zealand	...	13 250	2.7	1.6	20 204	...	4.4	...	4.0
Norway	...	35 620	3.1	2.5	35 433	...	2.6	...	5.0
Portugal	...	10 900	2.8	2.7	17 595	3.8	0.0	7 593	3.0
Spain	...	14 300	2.8	2.3	20 279	3.6	1.6	23 135	5.6
Sweden	...	25 400	1.8	1.3	24 924	1.7	0.1	37 609	3.0
Switzerland	...	38 330	1.2	0.4	28 204	...	...	...	...
United Kingdom	...	25 120	2.3	2.0	25 141	1.0	–0.7	31 160	0.7
United States of America	...	34 400	3.0	1.7	34 322	...	4.8	...	6.0
COUNTRIES IN TRANSITION	**...**	**1 940**	**–1.6**	**–1.9**	**6 713**	**8.2**	**–0.9**	**2 417**	**1.4**
Albania	...	1 340	2.0	1.4	3 738	34.2	4.8	2 160	5.6
Armenia	55.0	700	–1.0	0.1	2 598	27.7	1.4	5 893	4.4
Azerbaijan	68.1	650	–0.7	–1.8	2 824	17.3	–0.3	840	–0.9
Belarus	41.9	1 300	–0.2	–0.2	5 052	10.7	–2.9	2 346	1.6
Bosnia and Herzegovina	19.5	1 270	21.2	22.3	5 345	14.3	8.2	...	14.0
Bulgaria	...	1 670	–1.9	–0.9	6 625	13.9	2.9	8 624	8.4
Croatia	...	4 410	–0.4	0.2	9 462	9.7	–2.2	10 172	5.1
Czech Republic	...	5 320	0.6	1.8	14 495	4.2	7.7	6 167	2.5
Estonia	8.9	3 870	–1.0	–0.2	10 959	5.9	–5.6	4 202	0.5
Georgia	11.1	600	–9.6	–6.8	2 053	22.1	...	...	...
Hungary	17.1	4 830	1.0	0.9	12 656	...	–3.4	...	–0.3
Kazakhstan	34.6	1 340	–2.3	–1.4	5 225	9.0	–2.2	1 842	–3.0

TABLE A7 *(cont.)*

	Poverty headcount, national *(% of population)*	GNP per capita *(Current US$)*	GDP *(Annual % growth)*	GDP per capita *(Annual % growth)*	GDP per capita, PPP *(Current interna-tional $)*	Agriculture, value added *(% of GDP)*	*(Annual % growth)*	Agriculture, value added per worker *(Constant 1995 US$)*	*(Annual % growth)*
	Latest year	**2001**	**1990–2001**	**1990–2001**	**2001**	**2001**	**1990–2001**	**2001**	**1990–2001**
Kyrgyzstan	64.1	280	–1.9	–2.8	1 598	37.3	2.2	1 727	3.5
Latvia	...	3 260	–2.4	–1.5	8 241	4.5	–5.2	2 885	0.0
Lithuania	...	3 340	–1.9	–1.2	9 324	7.1	1.4	3 153	5.6
Macedonia, The Former Yugoslav Republic of	...	1 700	–0.4	–1.0	6 232	11.8	0.9	4 090	2.6
Moldova, Republic of	23.3	4 00	–8.1	–7.1	1 346	26.0	–7.3	1 778	–5.7
Poland	23.8	4 340	3.7	3.4	10 021	3.6	–0.1	1 616	1.4
Romania	21.5	1 710	–1.4	–1.2	6 024	15.0	3.1	3 938	7.7
Russian Federation	30.9	1 750	–3.3	–2.9	7 653	6.7	–2.9	2 950	–0.6
Slovakia	...	3 760	0.7	1.7	11 781	4.1	1.0	...	5.7
Slovenia	...	9 760	2.3	2.1	17 137	3.1	–0.7	39 351	10.7
Tajikistan	...	180	–7.2	–7.3	850	29.4	–5.0	...	–1.4
Turkmenistan	...	950	0.5	–2.7	4 104	28.8	3.5	1 787	3.1
Ukraine	31.7	720	–7.1	–5.9	4 459	16.6	–4.5	1 715	1.5
Uzbekistan	...	550	0.6	–1.2	1 561	34.1	1.7	1 127	1.5

TABLE A8
Total factor productivity

	Total factor productivity change		Efficiency change		Technological change	
	1961–81	1981–2000	1961–81	1981–2000	1961–81	1981–2000
DEVELOPING COUNTRIES	**–2.6**	**1.7**	**0.0**	**–0.4**	**–2.6**	**2.0**
ASIA AND THE PACIFIC	**–3.5**	**1.9**	**–0.1**	**–0.6**	**–3.4**	**2.5**
Bangladesh	–3.2	1.1	0.0	0.0	–3.2	1.1
China, Mainland	–4.4	3.6	0.0	0.0	–4.4	3.6
China, Taiwan Province of	0.5	0.3	0.0	0.0	0.5	0.3
Fiji Islands	–0.4	–0.3	–0.1	–2.3	–0.2	2.0
India	–5.2	–1.0	0.0	–2.7	–5.2	1.7
Indonesia	–0.5	–1.1	0.0	0.0	–0.5	–1.1
Korea, Democratic People's Republic of	1.0	1.6	–1.4	1.3	2.5	0.2
Korea, Republic of	–4.5	–1.2	0.0	0.0	–4.5	–1.2
Lao People's Dem. Rep. of	–0.2	3.3	–0.6	1.9	0.5	1.4
Malaysia	1.8	1.5	0.0	0.0	1.8	1.5
Mongolia	–8.3	3.9	–0.7	1.4	–7.7	2.5
Myanmar	0.0	1.8	0.6	0.5	–0.6	1.3
Nepal	–3.8	1.2	–0.2	0.0	–3.6	1.2
Pakistan	–0.7	2.7	–1.8	0.2	1.1	2.5
Philippines	1.3	0.4	0.0	0.0	1.3	0.4
Sri Lanka	0.7	–0.2	0.2	–1.0	0.6	0.8
Thailand	0.2	1.4	0.2	0.0	–0.1	1.4
Viet Nam	0.4	1.0	–0.2	–0.6	0.7	1.6
LATIN AMERICA AND THE CARIBBEAN	**–1.2**	**0.4**	**0.1**	**–0.1**	**–1.3**	**0.5**
Argentina	–2.2	–3.4	0.0	0.0	–2.2	–3.4
Barbados	2.9	0.9	0.3	–1.8	2.6	2.7
Belize	2.0	1.0	1.4	–1.0	0.5	2.0
Bolivia	0.6	2.6	1.0	0.0	–0.4	2.6
Brazil	–3.0	1.1	0.0	0.0	–3.0	1.1
Chile	1.5	2.9	–0.2	0.1	1.7	2.8
Colombia	1.4	1.0	0.3	0.0	1.1	1.0
Costa Rica	2.6	2.8	1.0	0.3	1.6	2.4
Cuba	–0.9	0.2	–1.4	–1.6	0.5	1.8
Dominican Republic	0.2	0.5	0.0	0.0	0.2	0.5
Ecuador	–1.4	1.3	0.0	0.1	–1.3	1.2
El Salvador	1.4	–0.1	0.3	–1.3	1.1	1.2
Guadeloupe	–0.6	1.7	–2.4	0.1	1.8	1.6
Guatemala	2.1	0.8	0.7	0.0	1.4	0.8
Guyana	1.2	1.8	–0.3	0.8	1.5	1.0
Haiti	–1.4	–0.2	0.0	0.0	–1.4	–0.2
Honduras	–1.3	0.4	0.3	–0.6	–1.6	1.0
Jamaica	0.6	1.6	0.3	–0.8	0.2	2.4
Martinique	–1.5	2.1	–1.4	0.0	–0.1	2.1
Mexico	1.2	1.1	0.6	–0.6	0.6	1.7
Nicaragua	–4.3	1.5	–1.2	0.7	–3.1	0.9

TABLE A8 *(cont.)*

	Total factor productivity change		Efficiency change		Technological change	
	1961–81	1981–2000	1961–81	1981–2000	1961–81	1981–2000
Panama	–0.2	0.5	–1.1	–0.5	0.9	1.0
Paraguay	–0.5	–1.9	0.0	0.0	–0.5	–1.9
Peru	–0.9	2.5	–0.9	0.5	0.0	2.0
Saint Lucia	–0.7	–3.0	0.0	–2.9	–0.7	–0.2
Saint Vincent and the Grenadines	–1.0	0.2	–2.9	1.4	1.9	–1.2
Suriname	3.3	–4.3	1.8	–4.0	1.4	–0.3
Trinidad and Tobago	–1.6	0.5	–0.7	–1.2	–0.9	1.7
Uruguay	–1.5	0.6	0.0	0.0	–1.5	0.6
Venezuela	1.8	2.0	1.3	0.1	0.5	1.9
NEAR EAST AND NORTH AFRICA	**0.6**	**2.4**	**–0.2**	**0.2**	**0.7**	**2.1**
Afghanistan	–1.5	2.1	0.3	0.0	–1.7	2.1
Algeria	–0.8	3.2	–2.2	1.1	1.4	2.0
Cyprus	3.3	4.4	–0.8	0.4	4.2	4.1
Egypt	1.1	2.1	0.0	0.0	1.1	2.1
Iran, Islamic Republic of	0.2	2.3	–0.2	0.0	0.3	2.3
Iraq	–3.1	–1.0	–2.3	–1.9	–0.8	0.9
Jordan	–3.4	1.6	–1.0	–0.1	–2.4	1.7
Lebanon	3.8	2.7	0.0	0.0	3.8	2.7
Libyan Arab Jamahiriya	4.6	4.5	3.5	2.0	1.1	2.4
Morocco	1.7	2.9	0.6	1.2	1.1	1.7
Saudi Arabia	–3.3	4.8	–1.9	2.4	–1.4	2.3
Syrian Arab Republic	1.4	0.3	0.0	–0.1	1.4	0.4
Tunisia	3.3	2.0	0.7	2.2	2.5	–0.2
Turkey	1.0	2.7	0.0	0.0	1.0	2.7
Yemen	–10.3	2.1	–3.3	1.6	–7.3	0.4
SUB-SAHARAN AFRICA	**–3.7**	**1.9**	**0.1**	**0.0**	**–3.8**	**2.0**
Angola	–3.7	5.3	–3.5	4.1	–0.2	1.1
Benin	0.5	2.4	0.5	0.3	0.1	2.0
Botswana	–2.4	–2.2	–0.2	–1.0	–2.2	–1.2
Burkina Faso	–9.0	–0.5	–1.0	–2.5	–8.1	2.0
Burundi	–11.5	–0.4	0.0	0.0	–11.5	–0.4
Cameroon	–6.8	1.1	0.0	.00	–6.8	1.1
Chad	–3.1	0.2	0.0	0.0	–3.1	0.2
Congo, Rep. of the	–2.3	–1.4	0.0	0.0	–2.3	–1.4
Côte d'Ivoire	–4.1	1.9	0.0	0.0	–4.1	1.9
Eritrea	...	–1.9	...	–2.2	...	0.3
Ethiopia	...	3.7	...	0.0	...	3.7
Gabon	–5.2	2.9	0.0	0.0	–5.2	2.9
Gambia	–4.6	–0.7	–2.8	–0.5	–1.9	–0.2
Ghana	–6.6	4.3	0.0	0.0	–6.6	4.3
Guinea	–2.4	–1.4	0.0	0.0	–2.4	–1.4
Kenya	0.8	1.1	2.1	–0.4	–1.3	1.5
Lesotho	–2.9	–0.5	–2.7	–1.1	–0.2	0.6
Madagascar	–0.9	0.6	0.0	0.0	–0.9	0.6

TABLE A8 *(cont.)*

	Total factor productivity change		Efficiency change		Technological change	
	1961–81	1981–2000	1961–81	1981–2000	1961–81	1981–2000
Malawi	–0.8	2.6	–1.3	1.6	0.4	1.0
Mali	–5.2	–1.6	0.0	–2.2	–5.2	0.6
Mauritius	0.6	–0.3	0.0	0.0	0.6	–0.3
Mozambique	–2.3	0.6	0.0	–0.2	–2.3	0.8
Niger	–6.3	1.3	0.0	0.0	–6.3	1.3
Nigeria	–10.5	3.6	0.0	0.0	–10.5	3.6
Rwanda	1.6	0.6	0.0	0.0	1.6	0.6
Réunion	2.0	5.8	–1.1	2.6	3.2	3.1
Senegal	–3.4	0.2	–2.3	–0.3	–1.1	0.5
Sierra Leone	–0.6	1.5	–0.7	1.1	0.1	0.4
Sudan	–0.7	2.0	0.0	0.0	–0.7	2.0
Swaziland	–0.4	1.9	0.1	0.5	–0.5	1.4
Tanzania, United Rep. of	1.1	2.2	1.7	0.0	–0.6	2.2
Togo	–3.6	1.3	0.4	–0.3	–3.9	1.6
Uganda	1.6	–3.8	0.0	0.0	1.6	–3.8
Zambia	–0.4	1.4	–0.1	–1.2	–0.3	2.6
Zimbabwe	0.7	0.8	–0.7	–0.4	1.4	1.3
	1961–81	**1993–2000**	**1961–81**	**1993–2000**	**1961–81**	**1993–2000**
COUNTRIES IN TRANSITION	**...**	**1.9**	**...**	**0.0**	**...**	**1.8**
Albania	...	5.8	...	4.0	...	1.7
Armenia	...	7.5	...	7.3	...	0.2
Azerbaijan	...	8.1	...	6.1	...	1.9
Belarus	...	–1.7	...	–2.4	...	0.7
Bosnia and Herzegovina	...	–3.4	...	–2.8	...	–0.7
Bulgaria	...	4.3	...	1.4	...	2.9
Croatia	...	2.4	...	0.0	...	2.4
Czech Republic	...	–2.0	...	0.0	...	–2.0
Estonia	...	0.3	...	1.7	...	–1.4
Georgia	...	–0.4	...	–0.9	...	0.5
Hungary	...	0.0	...	0.0	...	0.0
Kazakhstan	...	8.1	...	1.5	...	6.5
Kyrgyzstan	...	3.9	...	1.5	...	2.1
Latvia	...	–0.9	...	0.0	...	–0.9
Lithuania	...	–2.1	...	–1.3	...	–0.8
Macedonia, The Former Yugoslav Republic of	...	–6.9	...	–4.9	...	–2.1
Moldova, Republic of	...	5.7	...	2.9	...	2.8
Poland	...	–0.2	...	0.0	...	–0.2
Romania	...	0.6	...	–0.9	...	1.5
Russian Federation	...	3.3	...	0.0	...	3.3
Serbia and Montenegro	...	–1.3	...	0.0	...	–1.3
Slovakia	...	–2.4	...	–1.7	...	–0.8
Slovenia	...	2.3	...	0.0	...	2.3
Tajikistan	...	6.1	...	4.2	...	1.8
Turkmenistan	...	0.7	...	–1.5	...	2.2
Ukraine	...	2.8	...	0.0	...	2.8
Uzbekistan	...	–0.2	...	–1.2	...	1.0

- **References**
- **Special chapters of**
  The State of Food and Agriculture
- **Selected publications**
- **SOFA-DB CD-ROM**
  Installation and start-up guidelines

References

AEBC (Agriculture and Environment Biotechnology Commission). 2002. *Animals and biotechnology: a report by the AEBC*. London, Department of Trade and Industry.

Alston, J.M., Norton, G.W. & Pardey, P.G. 1995. *Science under scarcity: principles and practice for agricultural research evaluation and priority setting*. Ithaca, NY, USA, Cornell University Press.

Alston, J.M., Marra, M.C., Pardey, P.G. & Wyatt, T.J. 2000. Research returns redux: a meta-analysis of the returns to agricultural R&D. *Aust. J. Agr. Resour. Econ.*, 44(2): 185–215.

Bennett, R., Morse, S. & Ismael, Y. 2003. *The benefits of Bt cotton to small-scale producers in developing countries: the case of South Africa*. Paper presented at the 7th ICABR International Conference on Public Goods and Public Policy for Agricultural Biotechnology, Ravello, Italy, 29 June to 3 July 2003 (available at http://www.economia.uniroma2.it/conferenze/icabr2003/papers/papers.htm; accessed March 2004).

Byerlee, D. & Fischer, K. 2002. Accessing modern science: policy and institutional options for agricultural biotechnology in developing countries. *World Dev.*, 30(6): 931–948.

Byerlee, D. & Hesse de Polanco, E. 1986. Farmers' stepwise adoption of technological packages: evidence from the Mexican Altiplano. *Am. J. Agr. Econ.*, 68(3): 519–527.

Byerlee, D. & Moya, P. 1993. *Impacts of international wheat breeding research in the developing world, 1966–1990*. Mexico City, International Maize and Wheat Improvement Center.

Byerlee, D. & Traxler, G. 2002. The role of technology spillovers and economies of size in the efficient design of agricultural research systems. *In* J.M. Alston, P.G. Pardy & M.J. Taylor, eds. *Agricultural science policy: changing global agendas*. Baltimore, USA, Johns Hopkins University Press.

Cabanilla, L.S., Abdoulaye & T. Sanders, J.H. 2003. *Economic cost of non-adoption of Bt cotton in West Africa: with special reference to Mali.* Paper presented at the 7th ICABR International Conference on Public Goods and Public Policy for Agricultural Biotechnology, Ravello, Italy, 29 June to 3 July 2003 (available at http://www.economia.uniroma2.it/conferenze/icabr2003/papers/papers.htm; accessed March 2004).

Cardellino, R., Hoffmann, I. & Tempelman, K.A. 2003. *First report on the state of the world's animal genetic resources: views on biotechnologies as expressed in country reports*. Paper presented at the International Symposium on Applications of Gene-based Technologies for Improving Animal Production and Health in Developing Countries, 6–10 October 2003, Vienna. Organized by FAO and IAEA.

Carpenter, J.E. & Gianessi, L.P. 2001. *Agricultural biotechnology: updated benefits estimates*. Washington, DC, National Center for Food and Agricultural Policy.

Chambers, P. & Heritage, J. 2004. Transgenic crops and antibiotic marker genes. *AGRIPPA* (FAO peer-reviewed electronic journal), forthcoming (available at http://www.fao.org/agrippa).

Charles, A. 2003. Creation of GM potato to fight hunger sets India's scientists against green groups. *The Independent*, 3 January.

CIAT (International Center For Tropical Agriculture) & IFPRI (International Food Policy Research Institute). 2002. *Biofortified crops for improved human nutrition. A Challenge Program Proposal* (available at http://www.cgiar.org/pdf/biofortification.pdf; accessed March 2004).

Coghlan, A. 2003. Genetically modified "protato" to feed India's poor. *New Scientist*, 2 January.

Conner, A.J., Glare, T.R. & Nap, J.-P. 2003. The release of genetically modified crops into the environment: Part II. Overview of ecological risk assessment. *Plant J.*, 33: 19–46.

Conway, G. 2000. *Crop biotechnology: benefits, risks and ownership*. Speech by President of the Rockefeller Foundation delivered at the OECD Edinburgh Conference on the Scientific and Health Aspects of Genetically Modified Foods (available under news archive at http://www.rockfound.org; accessed March 2004).

Corneille, S., Lutz, K., Svab, Z. & Maliga, P. 2001. Efficient elimination of selectable marker genes from the plastid genome by the CRE-lox site-specific recombination system. *Plant J.*, 27: 171–178.

DANIDA (Danish International Development Agency). 2002. *Assessment of potentials and constraints for development and use of plant* *biotechnology in relation to plant breeding and crop production in developing countries.* DANIDA Working Paper 104. DAN.4-52-5.b. Copenhagen, Ministry of Foreign Affairs.

David, C. & Otsuka, K., eds. 1994. *Modern rice technology and income distribution in Asia*. Boulder, CO, USA, Lynne Rienner Publishers.

De Vetten, N., Wolters, A.M., Raemakers, K., Van Der Meer, I., Ter Stege, R., Heeres, E., Heeres, P. & Visser, R. 2003. A transformation method for obtaining marker-free plants of a cross-pollinating and vegetatively propagated crop. *Nat. Biotechnol.*, 21(4): 439–442.

Delgado, L.C., Hopkins, J. & Kelly, V.A. 1998. *Agricultural growth linkages in sub-Saharan Africa*. IFPRI Research Report No. 107. Washington, DC, International Food Policy Research Institute.

Dreher, K., Morris, M., Khairallah, M., Ribaut, J.M., Pandey, S. & Srinivasan, G. 2000. *Is marker-assisted selection cost-effective compared to conventional plant breeding methods? The case of quality protein maize*. Paper presented at the 4th ICABR Conference on Economics of Agricultural Biotechnology, Ravello, Italy, 24–28 August 2000.

Duffy, M. 2001. *Who benefits from biotechnology?* Paper presented at the American Seed Trade Association meeting, Chicago, IL, USA, 5–7 December (available at http://www.leopold.iastate.edu/pubinfo/papersspeeches/biotech.html; accessed March 2004).

Einsiedel, E.F. 1998. The market for credible information in biotechnology. Biotechnology and the Consumer. *In* B.M. Knoppers & A.M. Mathios, eds. *Biotechnology and the consumer: a research project sponsored by the Office of Consumer Affairs of Industry Canada*, pp. 47–85. Dordrecht, Netherlands, Kluwer Academic Publishers.

Environics International. 2000. *International Environmental Monitor 2000*. Toronto, Canada.

Environics International. 2001. *Food Issues Monitor 2001*. Toronto, Canada.

Evenson, R.E. & Gollin, D. 2003. Assessing the impact of the green revolution: 1960–2000. *Science*, 300: 758–762.

Falck-Zepeda, J.B., Traxler, G. & Nelson, R.G. 1999. *Rent creation and distribution from the first three years of planting Bt cotton*. ISAAA Briefs No. 14. Ithaca, USA, International Service for the Acquisition of Agri-biotech Applications.

Falck-Zepeda, J.B., Traxler, G. & Nelson, R.G. 2000a. Surplus distribution from the introduction of a biotechnology innovation. *Am. J. Agr. Econ.*, 82(2): 360–369.

Falck-Zepeda, J.B., Traxler, G. & Nelson, R.G. 2000b. Rent creation and distribution from biotechnology innovations: the case of Bt cotton and herbicide-tolerant soybeans in 1997. *Agribusiness*, 16(1): 1–23.

Fan, S., Hazell, P. & Thorat, S. 1998. *Government spending, growth, and poverty: an analysis of interlinkages in rural India*. EPTD Discussion Paper No. 33. Washington, DC, International Food Policy Research Institute.

FAO. 2000a. *The State of Food Insecurity in the World 2000*. Rome.

FAO. 2000b. *FAO statement on biotechnology* (available at http://www.fao.org/biotech/state.asp; accessed March 2004).

FAO. 2001a. *Glossary of biotechnology for food and agriculture: a revised and augmented edition of the glossary of biotechnology and genetic engineering*. Rome, FAO Research and Technology Paper 9 (also available at http://www.fao.org/biotech/index_glossary.asp?lang=en; accessed March 2004).

FAO. 2001b. *Pest risk analysis for quarantine pests*. ISPM Pub. No. 11. Rome.

FAO. 2002a. *Crop biotechnology: a working paper for administrators and policy makers in sub-Saharan* Africa, by L. Kitch, M. Koch & I. Sithole Niang. Harare.

FAO. 2002b. *Report of the Fourth Interim Commission on Phytosanitary Measures*. 11–15 March 2002, Rome (available at http://www.ippc.int/IPP/En/icpm_docs.jsp; accessed March 2004).

FAO. 2003. *FAOSTAT (FAO statistical databases)* (available at http://apps.fao.org/default.htm; accessed March 2004).

FAO/WHO. 2000. *Safety aspects of genetically modified foods of plant origin*. Report of a Joint FAO/WHO Expert Consultation on Foods Derived from Biotechnology, Geneva, Switzerland. 29 May–2 June 2000 (available at ftp://ftp.fao.org/es/esn/food/gmreport.pdf; accessed March 2004)

FAO/WHO. 2001. Codex general standard for the labelling of prepackaged foods. Codex Stan. 1-1985 (Rev. 1-1991). In *Codex Alimentarius. Food labelling. Complete texts*. Revised 2001. Rome.

FAO/WHO. 2003a. *Principles for the risk analysis of foods derived from modern biotechnology.* Rome (available at ftp://ftp.fao.org/es/esn/food/princ_gmfoods_en.pdf; accessed March 2004).

FAO/WHO. 2003b. *Guideline for the conduct of food safety assessment of foods derived from* *recombinant-DNA plants.* Rome (available at ftp://ftp.fao.org/es/esn/food/guide_plants_en.pdf; accessed March 2004).

FAO/WHO. 2003c. *Guideline for the conduct of food safety assessment of foods produced using recombinant-DNA microorganisms*. Rome (available at ftp://ftp.fao.org/es/esn/food/guide_mos_en.pdf; accessed March 2004).

FAO/WHO. 2003d. *Codex Alimentarius Commission. Report of the Twenty-Sixth Session*, 30 June–7 July 2003, Rome (available at ftp://ftp.fao.org/codex/alinorm03/al03_41e.pdf; accessed March 2004).

FAO/WHO. 2003e. *Report of the Thirtieth Session of the Codex Committee on Food Labelling*. 6–10 May 2002, Halifax, Canada (available at ftp://ftp.fao.org/codex/alinorm03/Al03_22e.pdf; accessed March 2004).

Fernandez-Cornejo, J. & McBride, W.D. 2000. *Genetically engineered crops for pest management in US agriculture: farm level effects*. Agricultural Economic Report No. 786. Washington, DC, Economic Research Service, United States Department of Agriculture.

Five Year Freeze. 2002. *Feeding or fooling the world? Can GM really feed the world?* (available at http://www.fiveyearfreeze.org/Feed_Fool_World.pdf; accessed March 2004).

Frewer, L.J. & Shepherd, R.S. 1994. Attributing information to different sources: effects on the perceived qualities of information, on the perceived relevance of information, and on attitude formation. *Public Underst. Sci*., 3: 385–401.

General Accounting Office. 2000. *Information on prices of genetically modified seeds in the United States and Argentina*. Washington, DC, United States General Accounting Office.

Gianessi, L.P., Silvers, C.S., Sankula, S. & Carpenter, J.E. 2002. *Plant biotechnology: current and potential impact for improving pest management in US agriculture: an analysis of 40 case studies*. Washington, DC, National Center for Food and Agricultural Policy.

Gisselquist, D., Nash, J. & Pray, C.E. 2002. Deregulating technology transfer in agriculture: impact on technical change, productivity, and incomes. *World Bank Research Observer*, 17: 237–265.

GM Science Review Panel. 2003. *GM Science Review: First report – an open review of the science relevant to GM crops and food based on the interests and concerns of the public*. London, Department of Trade and Industry (also available at http://www.gmsciencedebate.org.uk/report/default.htm; accessed March 2004).

Golan, E., Kuchler, F. & Mitchell, L. 2000. *Economics of food labelling*. Washington, DC, United States Department of Agriculture.

Graff, G. & Zilberman, D. 2001. An intellectual property clearinghouse for agricultural biotechnology. *Nature Biotechnology*, 19: 1179–1181.

Graham, R.D., Welch, R.M. & Bouis, H.E. 2001. Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: principles, perspectives and knowledge gaps. *Advances in Agronomy*, 70: 77–142.

Hayami, Y., Kikuchi, M., Moya, P.F., Bambo, L.M. & Marciano, E.B. 1978. *Anatomy of a peasant economy: a rice village in the Philippines*. Los Baños, International Rice Research Institute.

Hayami, Y. & Ruttan, V.W. 1985, *Agricultural development: an international perspective*, 2nd edn. Baltimore, USA, Johns Hopkins University Press.

Hazell, P. & Haggblade, S. 1993. Farm–nonfarm growth linkages and the welfare of the poor. *In* M. Lipton & J. van de Gaag, eds. *Including the poor*. Washington, DC, World Bank.

Herdt, R.W. 1987. A retrospective view of technological and other changes in Philippine rice farming, 1965–1982. *Econ. Dev. Cult. Change*, 35(2): 329–349.

Hoban, T. 2004. *Public attitudes towards agricultural biotechnology*. ESA Working Paper, forthcoming. Rome, FAO.

ICSU (International Council for Science). 2003. *New genetics, food and agriculture: scientific discoveries – societal dilemmas*. Paris (also available at http://www.icsu.org).

James, C. 1999. *Global review of commercialized transgenic crops: 1999*. ISAAA Briefs No. 12: Preview. Ithaca, NY, USA, International Service for the Acquisition of Agri-biotech Applications.

James, C. 2002a. *Preview: global status of commercialized transgenic crops: 2002*. ISAAA Briefs No. 27. Ithaca, NY, USA, International Service for the Acquisition of Agri-biotech Applications.

James, C. 2002b. *Global review of commercialized transgenic crops: 2001 (Feature: Bt cotton)*. ISAAA Briefs No. 26. Ithaca NY, USA, International Service for the Acquisition of Agri-biotech Applications.

James, C. 2003. *Preview*: *Global status of commercialized transgenic crops: 2003*. ISAAA Briefs No. 30. Ithaca, NY, USA, International Service for the Acquisition of Agri-biotech Applications (also available at http:

//www.isaaa.org/kc/CBTNews/press_release/briefs30/es_b30.pdf; accessed March 2004)

Kirsten, J. & Gouse, M. 2003. The impact of agricultural biotechnology in South Africa. *In* N. Kalaitzandonakes, ed. *The economic and environmental impacts of agbiotech: a global perspective*. New York, USA, Kluwer-Plenum Academic Publishers.

Knoppers, B.M. & Mathios, A.M., eds. 1998. *Biotechnology and the consumer: a research project sponsored by the Office of Consumer Affairs of Industry Canada*. Dordrecht, Netherlands, Kluwer Academic Publishers.

Lantican, M. & Pingali, P.L. 2003. Growth in wheat yield potential in marginal environments. In *Proceedings of the Warren E. Kronstad Memorial Symposium*, 1–17 March 2001. Mexico City, International Maize and Wheat Improvement Center.

Lipton, M. 2001. Reviving global poverty reduction: what role for genetically modified plants? *J. Int. Devel*., 13: 823–846.

Losey, J.E., Rayor, L.S. & Carter, M.E. 1999. Transgenic pollen harms monarch larvae. *Nature*, 399(6733): 214.

MacKenzie, D. & McLean, M. 2002. Who's afraid of GM feeds? *Feed Mix* 10(3): 16–19 (also available at http://www.agbios.com/docroot/articles/02-232-001.pdf; accessed March 2004).

Malmquist, S. 1953. Index numbers and indifference surfaces. *Trabajos de Estatistica,* 4: 209–242.

Maredia, M.K., Byerlee, D. & Eicher, C.K. 2004. *The efficiency of global wheat research investments: implications for research evaluation, research managers and donors*. Staff Paper No. 94–17. Department of Agricultural Economics, Michigan State University, USA.

Morris, M. 1998. *Maize seed industries in developing countries*. Boulder, CO, USA, Lynne Rienner Publishers.

Moschini, G., Lapan, H. & Sobolevsky, A. 2000. Roundup Ready® Soybeans and welfare effects in the soybean complex. *Agribusiness*, 16: 33–35.

Naik, G. 2001. *An analysis of socio-economic impact of Bt technology on Indian cotton farmers*. Ahmedabad, India, Centre for Management in Agriculture, Indian Institute of Management.

Naylor, R., Nelson, R., Falcon, W., Goodman, R., Jahn, M., Kalazich, J., Sengooba, T. & Tefera, H. 2002. *Integrating new genetic technologies into the improvement of orphan crops in least developed countries*. Presented at the 6th ICABR International Conference on Agricultural Biotechnologies: New Avenues for Production, Consumption and Technology Transfer, Ravello, Italy, 11–14 July 2002 (available at http://www.economia.uniroma2.it/conferenze/icabr/download/papers2002download.htm; accessed March 2004).

NRC (National Research Council). 2002. *Animal biotechnology. Science based concerns*. Washington, DC, The National Academies Press.

Nuffield Council on Bioethics. 1999. *Genetically modified crops: the ethical and social issues*. London.

Nuffield Council on Bioethics. 2003. *The use of genetically modified crops in developing countries*. Draft for comment, June 2003. London.

Pemsl, D.E., Waibel, H. & Gutierrez, A.P. 2003. *Productivity analysis of Bt cotton: a modelling approach based on a case study in Shandong Province, China*. Paper presented at the 7th ICABR International Conference on Public Goods and Public Policy for Agricultural Biotechnology, Ravello, Italy, 29 June to 3 July 2003 (available at http://www.economia.uniroma2.it/conferenze/icabr2003/papers/papers.htm; accessed March 2004).

Pew Initiative on Food and Biotechnology. 2002a. *Three years later: genetically engineered corn and the monarch butterfly controversy*. Issue Brief (available at http://pewagbiotech.org/resources/issuebriefs/monarch.pdf).

Pew Initiative on Food and Biotechnology. 2002b. *How consumers process information at heart of debate over labeling of genetically modified foods*. News release (available at http://pewagbiotech.org/newsroom/releases/062702.php3; accessed March 2004).

Pew Initiative on Food and Biotechnology. 2003. *Future fish: issues in science and regulation of transgenic fish*. Washington, DC (also available at http://pewagbiotech.org/research/fish; accessed March 2004).

Pingali, P.L. & Heisey, P.W. 2001. Cereal-crop productivity in developing countries: past trends and future prospects. *In* J.M. Alston, P.G. Pardey & M. Taylor, eds. *Agricultural science policy*. Washington, DC, International Food Policy Research Institute and Johns Hopkins University Press.

Pingali, P.L. & Rajaram, S.R. 1999. *World wheat facts and trends, 1998/99*. Mexico City, International Maize and Wheat Improvement Center.

Pingali, P & Raney, T. 2003. *Globalization and agricultural biotechnology: impacts and* *implications for developing countries*. ESA Working Paper. Rome, FAO.

Pingali, P. & Traxler, G. 2002. Changing locus of agricultural research: will the poor benefit from biotechnology and privatization trends? *Food Policy*, 27: 223–238.

Pingali, P., Rozelle, S. & Gerpacio, R.V. 2001. The farmer's voice in priority setting: a cross-country experiment in eliciting technological preferences. *Econ. Dev. Cult. Change*, 49(3): 591–609.

Potrykus, I. 2003. *From "golden" to "nutritionally optimized" rice – and from a scientific concept to the farmer*. Presentation delivered at the conference "In the Wake of the Double Helix: from the Green Revolution to the Gene Revolution", Bologna, Italy, 27–31 May.

Pray, C.E. 2001. Public/private sector linkages in research and development: biotechnology and the seed industry in Brazil, China and India. *Am. J. Agr. Econ.*, 83(3): 742–747.

Pray, C.E. & Fuglie, K.O. 2000. *Policies for private agricultural research in Asian LDCs*. Paper presented at the XXIV International Conference of Agricultural Economists, Berlin, Germany.

Pray, C.E. & Huang, J. 2003. The impact of Bt cotton in China. *In* N. Kalaitzandonakes, ed. *The economic and environmental impacts of agbiotech: a global perspective.* New York, USA, Kluwer-Plenum Academic Publishers.

Pray, C.E. & Naseem, A. 2003a. *The economics of agricultural biotechnology research*. ESA Working Paper 03-07. Rome, FAO.

Pray, C.E. & Naseem, A. 2003b. *Biotechnology R&D: policy options to ensure access and benefits for the poor*. ESA Working Paper 03-08. Rome, FAO.

Pray, C.E. & Ramaswami, B. 2001. Technology, IPRs, and reform options: a case study of the seed industry with implications for other input industries. *The International Food and Agricultural Marketing Review, Special Issue*, 2.

Pray, C.E., Courtmanche, A. & Govindasamy, R. 2002. *The importance of intellectual property rights in the international spread of private sector agricultural biotechnology*. Paper presented at the 6th ICABR International Conference on Agricultural Biotechnologies: New Avenues for Production, Consumption and Technology Transfer, Ravello, Italy, 11–14 July 2002 (available at http://www.economia.uniroma2.it/conferenze/icabr/download/papers/2002download.htm; accessed March 2004).

Pray, C.E., Huang, J., Hu, R. & Rozelle, S. 2002. Five years of Bt cotton in China – the benefits continue. *The Plant Journal*, 31(4): 423–430.

Pray, C.E., Huang, J., Ma, D. & Qiao, F. 2001. Impact of Bt cotton in China. *World Dev.*, 29(5): 813–825.

Qaim, M. & Zilberman, D. 2003. Yield effects of genetically modified crops in developing countries. *Science*, 299: 900–902.

Qaim, M. & de Janvry, A. 2003. Genetically modified crops, corporate pricing strategies, and farmers' adoption: the case of Bt cotton in Argentina. *Am. J. Agr. Econ.*, 85(4): 814–828.

Qaim, M. & Traxler, G. 2004. Roundup ready Soybeans in Argentina: farm level, environmental, and welfare effect. *Agr. Econ.*, in press.

Renkow, M. 1993. Differential technology adoption and income distribution in Pakistan: implications for research resource allocation. *Am. J. Agr. Econ.*, 75(1): 33–43.

Rommens, C.M., Rudenko, G.N., Dijkwel, P.P., van Haaren, M.J., Ouwerkerk, P.B., Blok, K.M., Nijkamp, H.J. & Hille, J. 1992. Characterization of the Ac/Ds behaviour in transgenic tomato plants using plasmid rescue. *Plant Molec. Biol.*, 20(1): 61–70.

Royal Society. 2003. The Farm Scale Evaluations of spring-sown genetically modified crops. A themed issue. *Philos. Trans. R. Soc. Lond.* B, 358(1439): 1775–1913 (available at http://www.pubs.royalsoc.ac.uk/phil_bio/news/fse_toc.html; accessed March 2004).

Ruttan, V.W. 2001. Technology, growth and development: an induced innovation perspective. New York, USA, Oxford University Press.

Sadoulet, E. & de Janvry, A. 1995. *Quantitative development policy analysis*. Baltimore, USA, Johns Hopkins University Press.

Secretariat of the Convention on Biological Diversity. 1992. *Convention on Biological Diversity* (available at http://www.biodiv.org/convention/articles.asp; accessed March 2004).

Secretariat of the Convention on Biological Diversity. 2000. *Cartagena Protocol on Biosafety to the Convention on Biological Diversity: text and annexes*. Montreal, Canada (also available at http://www.biodiv.org/biosafety/protocol.asp; accessed March 2004).

Stahl, R., Horvath, H., Van Fleet, J., Voetz, M., von Wettstein, D. & Wolf, N. 2002. T-DNA integration into the barley genome from single and double cassette vectors. *Proc. Natl. Acad. Sci. USA*, 99: 2146–2151.

Stone, G.D. 2002. Both sides now: fallacies in the genetic modification wars, implications for developing countries, and anthropological perspectives. *Curr. Anthropol*., 43(4): 611–630.

Tegene, A., Huffman, W.E., Rousu, M. & Shogren, J.F. 2003. *The effects of information on consumer demand for biotech foods: evidence from experimental auctions*. Technical Bulletin No. 1903. Washington, DC, USDA Economic Research Service.

Thompson, P.B. 1997. *Food biotechnology in ethical perspective*. London, Blackie Academic & Professional.

Thro, A.M. & Spillane, C. 2000. *Biotechnology-assisted participatory plant breeding: complement or contradiction.* CGIAR System-wide Program on Participatory Research and Gender Analysis for Technology Development and Institutional Innovation. Working Document No. 4. Cali, Colombia, International Center for Tropical Agriculture.

Traxler, G. 2004. *Economic impacts of biotechnology-based technological innovations*. ESA Working Paper, forthcoming. Rome, FAO.

Traxler, G. & Byerlee, D. 1992. Economic returns to crop management research in post-green revolution setting. *Am. J. Agric. Econ.*, 74 (3): 573–582.

Traxler, G. & Pingali, P.L. 1999. *International collaboration in crop improvement research: current status and future prospects*. Economics Working Paper No. 99-11. Mexico City, International Maize and Wheat Improvement Center.

Traxler, G., Godoy-Avila, S., Falck-Zepeda, J. & Espinoza-Arellano, J. 2003. Transgenic cotton in Mexico: economic and environmental impacts. *In* N. Kalaitzandonakes, ed. *The economic and environmental impacts of agbiotech: a global perspective,* New York, USA, Kluwer-Plenum Academic Publishers.

USDA-AMS (United States Department of Agriculture, Agricultural Marketing Service). Various years. *Cotton varieties planted* (available at www.ams.usda.gov/cotton/mncs; accessed March 2004).

van der Walt, W.J. 2000. *Identifying increased production yield opportunities by monitoring biotechnology developments*. Presentation delivered at the 7th annual Agriculture Management Conference, VW Conference Centre, Midrand, South Africa, 25–26 October 2000.

WHO (World Health Organization). 2002. *20 questions on genetically modified (GM) foods* (available at http://www.who.int/foodsafety/publications/biotech/en/20questions_en.pdf; accessed March 2004).

Ye, X., Al-Babili, S., Klöti, A., Zhang, J., Lucca, P., Beyer, P. & Potrykus, I. 2000. Engineering the provitamin A (beta-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. *Science*, 287(5451): 303–305.

Zimmerman, R. & Qaim, M. 2002. *Projecting the benefits of golden rice in the Philippines*. Discussion Paper on Development Policy No. 51. Bonn, Germany, Centre for Development Research.

Zuo, J., Niu, Q.W., Ikeda, Y. & Chua, N.H. 2002. Marker-free transformation: increasing transformation frequency by the use of regeneration-promoting genes. *Curr. Opin. Biotechnol.*, 13(2): 173–180.

Special chapters of *The State of Food and Agriculture*

In addition to the usual review of the recent world food and agricultural situation, each issue of this report since 1957 has included one or more special studies on problems of longer-term interest. Special chapters in earlier issues have covered the following subjects:

1957 Factors influencing the trend of food consumption
Postwar changes in some institutional factors affecting agriculture

1958 Food and agricultural developments in Africa south of the Sahara
The growth of forest industries and their impact on the world's forests

1959 Agricultural incomes and levels of living in countries at different stages of economic development
Some general problems of agricultural development in less-developed countries in the light of postwar experience

1960 Programming for agricultural development

1961 Land reform and institutional change
Agricultural extension, education and research in Africa, Asia and Latin America

1962 The role of forest industries in the attack on economic underdevelopment
The livestock industry in less-developed countries

1963 Basic factors affecting the growth of productivity in agriculture
Fertilizer use: spearhead of agricultural development

1964 Protein nutrition: needs and prospects
Synthetics and their effects on agricultural trade

1966 Agriculture and industrialization
Rice in the world food economy

1967 Incentives and disincentives for farmers in developing countries
The management of fishery resources

1968 Raising agricultural productivity in developing countries through technological improvement
Improved storage and its contribution to world food supplies

1969 Agricultural marketing improvement programmes: some lessons from recent experience
Modernizing institutions to promote forestry development

1970 Agriculture at the threshold of the Second Development Decade

1971 Water pollution and its effects on living aquatic resources and fisheries

1972	Education and training for development
	Accelerating agricultural research in the developing countries
1973	Agricultural employment in developing countries
1974	Population, food supply and agricultural development
1975	The Second United Nations Development Decade: mid-term review and appraisal
1976	Energy and agriculture
1977	The state of natural resources and the human environment for food and agriculture
1978	Problems and strategies in developing regions
1979	Forestry and rural development
1980	Marine fisheries in the new era of national jurisdiction
1981	Rural poverty in developing countries and means of poverty alleviation
1982	Livestock production: a world perspective
1983	Women in developing agriculture
1984	Urbanization, agriculture and food systems
1985	Energy use in agricultural production
	Environmental trends in food and agriculture
	Agricultural marketing and development
1986	Financing agricultural development
1987–88	Changing priorities for agricultural science and technology in developing countries
1989	Sustainable development and natural resource management
1990	Structural adjustment and agriculture
1991	Agricultural policies and issues: lessons from the 1980s and prospects for the 1990s
1992	Marine fisheries and the law of the sea: a decade of change
1993	Water policies and agriculture
1994	Forest development and policy dilemmas
1995	Agricultural trade: entering a new era?
1996	Food security: some macroeconomic dimensions
1997	The agroprocessing industry and economic development
1998	Rural non-farm income in developing countries
2000	World food and agriculture: lessons from the past 50 years
2001	Economic impacts of transboundary plant pests and animal diseases
2002	Agriculture and global public goods ten years after the Earth Summit

Selected publications

FAO FLAGSHIP PUBLICATIONS

(available at www.fao.org/sof)

The State of Food and Agriculture
The State of Food Insecurity in the World
The State of World Fisheries and Aquaculture
State of the World's Forests

AGRICULTURAL AND DEVELOPMENT ECONOMICS DIVISION (ESA) PUBLICATIONS

(available at www.fao.org/es/esa)

BOOKS

Food, agriculture and rural development: current and emerging issues for economic analysis and policy research (CUREMIS II) Vol.1: Latin America and the Caribbean
(B. Davis, ed., 2003)

Nutrition intake and economic growth: studies on the cost of hunger
(Kiyoshi Taniguchi and Xiaojun Wang, eds, 2003)

Choosing a method for poverty mapping
(B. Davis, 2003)

Promoting farm/non-farm linkages for rural development: case studies from Africa and Latin America
(B. Davis, T. Reardon, K.G. Stamoulis and P. Winters, eds, 2002)

Food, agriculture and rural development: current and emerging issues for economic analysis and policy research (CUREMIS I)
(K.G. Stamoulis, ed., 2001)

ESA WORKING PAPERS

05-04 *Globalization of Indian diets and the transformation of food supply systems*
(P. Pingali and Y. Khwaja, February 2004)

04-04 *Agricultural policy indicators*
(T. Josling and A. Valdés, February 2004)

03-04 *Resource abundance, poverty and development*
(E.H. Bulte, R. Damania and R.T. Deacon, January 2004)

02-04 *Conflicts, rural development and food security in West Africa* (M. Flores, January 2004)

01-04 *Valuation methods for environmental benefits in forestry and watershed investment projects* (R. Cavatassi, January 2004)

22-03 *Linkages and rural non-farm employment creation: changing challenges and policies in Indonesia* (S. Kristiansen, December 2003)

21-03 *Information asymmetry and economic concentration: the case of hens and eggs in eastern Indonesia* (S. Kristiansen, December 2003)

20-03 *Do futures benefit farmers who adopt them?* (S.H. Lence, December 2003)

19-03 *The economics of food safety in developing countries* (S. Henson, December 2003)

18-03 *Food security and agriculture in the low income food deficit countries: 10 years after the Uruguay Round* (P. Pingali and R. Stringer, November 2003)

17-03 *A conceptual framework for national agricultural, rural development, and food security strategies and policies* (K.G. Stamoulis and A. Zezza, November 2003)

16-03 *Can public transfers reduce Mexican migration? A study based on randomized experimental data* (G. Stecklov, P. Winters, M. Stampini and B. Davis, October 2003)

15-03 *Diversification in South Asian agriculture: trends and constraints* (K. Dorjee, S. Broca and P. Pingali, July 2003)

14-03 *Determinants of cereal diversity in communities and on household farms of the northern Ethiopian Highlands* (S. Benin, B. Gebremedhin, M. Smale, J. Pender and S. Ehui, July 2003)

13-03 *Land use change, carbon sequestration and poverty alleviation* (L. Lipper and R. Cavatassi, July 2003)

12-03 *Social capital and poverty lessons from case studies in Mexico and Central America* (M. Flores and F. Rello, June 2003)

THE STATE OF FOOD AND AGRICULTURE

The State of Food and Agriculture 2003–04 explores the potential of agricultural biotechnology – especially transgenic crops – to meet the needs of the poor. It is found that agricultural biotechnology can help the poor by reducing reliance on toxic agricultural chemicals, lowering production costs for farmers, enhancing the nutritional content of foods and improving the control of plant and animal diseases. These gains can boost agricultural productivity and reduce food prices, but the benefits may not reach the poor. The report also presents an analysis of the socio-economic impacts of technological change in agriculture and surveys the current evidence regarding the safety of transgenic crops for human health and the environment. It recommends targeted investments in agricultural research, extension and regulatory capacity to ensure that the potential of agricultural biotechnology is brought to bear on the needs of the poor.

Included in this issue is the SOFA 2003–04 CD-ROM, containing time series data for 150 countries and regions in English, French and Spanish, together with FAOSTAT software for easy access and use.