

June 2004

Realizing the promise and potential of African agriculture

Science and technology strategies for
improving agricultural productivity
and food security in Africa



InterAcademy Council

Realizing the promise and potential of African agriculture







ISBN 90-6984-418-4

© Copyright InterAcademy Council, 2004

Non-commercial reproduction

Information in this report has been produced with the intent that it be readily available for personal and public non-commercial use and may be reproduced, in part or in whole and by any means, without charge or further permission from the InterAcademy Council. We ask only that:

- Users exercise due diligence in ensuring the accuracy of the materials reproduced;
- The InterAcademy Council be identified as the source; and
- The reproduction is not represented as an official version of the materials reproduced, nor as having been made in affiliation with or with the endorsement of the InterAcademy Council.

Commercial reproduction

Reproduction of multiple copies of materials in this report, in whole or in part, for the purposes of commercial redistribution is prohibited except with written permission from the InterAcademy Council. To obtain permission to reproduce materials in this report for commercial purposes, please contact the InterAcademy Council, c/o Royal Netherlands Academy of Arts and Sciences, P.O. Box 19121, NL-1000 GC Amsterdam, The Netherlands, secretariat@iac.knaw.nl

Design

Edita-KNAW, www.knaw.nl/edita

Photograph credits

Cover: Friedrich Stark/Das Fotoarchiv.

Pages 2-3: Andre de Jager (LEI-DLO)

Top of the pages: Charlotte Thege/Das Photoarchiv, Sean Sprague/Das Fotoarchiv, Charlotte Thege/Das Photoarchiv, Sebastian Bolesch/Das Fotoarchiv, STILL PICTURES/Das Fotoarchiv.



Foreword

In recent years, while there have been increases in food production in Africa, these increases have been offset by an even larger increase in human populations. While the availability of food per person since 1990 has increased by 30 percent in Asia and 20 percent in Latin America, it has gone down in Africa by 3 percent. Today many millions of people in southern Africa are on the brink of starvation.

In March 2002, the Secretary-General of the United Nations requested that the InterAcademy Council (IAC) prepare a strategic plan for harnessing the best science and technology to increase the productivity of agriculture in Africa. In response to the Secretary-General's request, the IAC Board invited the 90-national member academies of the InterAcademy Panel on International Issues (IAP) to nominate candidates for undertaking this study on the role of science and technology in improving agricultural productivity and food security in Africa. The IAC Board then appointed a Study Panel on Agricultural Productivity in Africa, composed of Co-Chairs Speciosa Kazibwe of Uganda, Rudy Rabbinge of the Netherlands, and M.S. Swaminathan of India, plus 15 other distinguished members. The Study Panel's personal experience in agricultural sciences and agricultural policies spans all regions of the world, including of course Africa; it also includes many scientific disciplines.

The charge to the Study Panel was to produce a consensus report for the United Nations that (1)

addresses how science and technology can help to improve agricultural production in Africa, and (2) identifies the larger economic, social, and political conditions that will be necessary for effective use of this science and technology in both the public and private sectors. The Study Panel began its work with a series of regional workshops throughout Africa, which allowed it to benefit immensely from the expertise and views of African scientists on the key agricultural issues facing Africa. Then the Study Panel held a series of meetings to develop its conclusions and recommendations.

The document that follows is the result. First written in draft form, the final report incorporates the Study Panel's response to an extensive external, independent and anonymous review process that involved 13 experts plus two distinguished scientists who served as review monitors. We thank all of the Study Panel members, reviewers, and monitors who contributed to this important effort. Special appreciation is due to the Study Panel's Co-Chairs and Study Director, who put much time and devotion into ensuring that the final product would make a difference.

The InterAcademy Council also gratefully acknowledges the leadership exhibited by the Bill and Melinda Gates Foundation, the Carnegie Corporation of New York, and the Netherlands Ministry of Development Cooperation, which provided the financial support for the conduct of the study and the distribution of this report.

As this report emphasizes, realizing the promise and potential of African agriculture requires long-range approaches that will need to involve a broad array of African institutions and constituencies. But every long journey begins with first steps, and we urge that the following be initiated as soon as possible:

- The UN Secretary General, in consultation with



the African Union, should identify the most appropriate regional, national and international institutions to implement the innovative pilot programs that are recommended, which are designed to shape Africa's agricultural future. There should be strong African involvement at every step.

- Interdisciplinary teams from African universities, research centers, extension services, and farmers' organizations should be created to prepare plans for promoting priority farming systems. Local farmers' advisory councils involving both men and women should be constituted to assume ownership and undertake monitoring and evaluation of the resulting initiatives.
- African national governments should create centers of agricultural research excellence to serve the interests of smallholder farm families. These centers should help to provide location-specific information relating to meteorological, management, and marketing factors – as well as to promote literacy on critical genetic, quality, and trade issues among smallholder farm families.

The scientific academies of the world, as close partners with their colleagues in Africa, stand ready to contribute their part to this great humanitarian effort of the early 21st century.

Bruce ALBERTS
President, U.S. National Academy of Sciences
Co-Chair, InterAcademy Council

Goverdhan MEHTA
Former President, Indian National Science Academy
Co-Chair, InterAcademy Council



Contents

Foreword	v
Study panel	ix
Preface	xi
Report review	xiii
Acknowledgements	xv
Executive summary	xvii
1. Introduction	i
2. Food security in Africa	9
3. African agricultural production systems and productivity in perspective	23
4. Science and technology options that can make a difference	67
5. Building impact-oriented research, knowledge and development institutions	115
6. Creating and retaining a new generation of agricultural scientists	169
7. Markets and policies to make the poor income and food secure	189
8. Strategic recommendations	209
Annexes	
A. Priority issues that emerged from African regional consultative workshops	235
B. Strategic actions for target audiences	241
C. Study panel biographies	251
D. Glossary	257
E. Abbreviations and acronyms	259
F. List of boxes, figures, and tables	263



Study panel

Co-Chairs

- Speciosa Wandira KAZIBWE**, Former Vice-President of the Republic of Uganda
- Rudy RABBINGE**, Dean, Graduate Schools, Wageningen Agricultural University, The Netherlands
- M.S. SWAMINATHAN**, Chairman, M.S. Swaminathan Research Foundation, India

Members

- Mohamed BESRI**, Professor, Hassan II Institute of Agronomy & Veterinary Medicine, Morocco
- Maria Manuela CHAVES**, Professor, Faculty of Agronomy, Technical University of Lisbon, Portugal
- Avilio Antonio FRANCO**, Member, Agronomy Advisory Committee, Brazilian Research Council, Brazil
- Ryuichi ISHII**, Professor, College of Bio-resource Science, Nihon University, Japan
- Jikun HUANG**, Director, Center for Chinese Agricultural Policy, Chinese Academy of Sciences, China
- Renald LAFOND**, Senior Program Specialist, ICT for Development, International Development Research Centre, Canada
- Peter MATLON**, Deputy Director for Food Security, Rockefeller Foundation, United States
- Ahmadou Lamine NDIAYE**, Vice-President, Academy of Sciences and Technology of Senegal
- Bongiwe NJOBE**, Director General, National Department of Agriculture, South Africa

Emmanuel Uche ODIGBOH, Professor, Agricultural Engineering Department, University of Nigeria

Gideon ORON, Professor, Environment Water Resources Unit, Institute for Desert Research, Ben-Gurion University of the Negev, Israel

Per PINSTRUP-ANDERSEN, Professor, Cornell University, USA, and The Royal Veterinary and Agricultural University, Denmark

Elly N. SABIITI, Former Dean, Faculty of Agriculture, Makerere University, Uganda

José SARUKHAN, Professor, Instituto de Ecología, National University of Mexico (UNAM), Mexico

Jennifer THOMSON, Professor, Department of Molecular Biology, University of Cape Town, South Africa.

Special Adviser

Louise FRESCO, Assistant Director General, Food and Agriculture Organization of the United Nations, Rome, Italy

Directorate

- Jim RYAN**, *Study Director*, Visiting Fellow, Economics Division, Research School of Pacific and Asian Studies, Australian National University
- Prem BINDRABAN**, *Associate Study Director*, Team Leader, Natural Resources, Agrosystems-research, Wageningen Agricultural University and Research Centre, The Netherlands
- Huub LÖFFLER**, *Research Associate*, Team Leader, Food and Health, BU Genetics and Breeding, Wageningen Agricultural University and Research Centre, The Netherlands



Preface

Africa is recognized as a continent of promise and potential, much as yet unrealized. Agriculture is pivotal to the realization of these aspirations as it contributes 70 percent of employment, 40 percent of exports and one-third of gross domestic product. Agricultural development in rural Africa, where three-quarters of the continent's food and nutrition insecure reside, would offer these communities relief and hope for a brighter future. Enhancing African agricultural productivity is a prerequisite for eradicating African poverty and associated food and nutrition insecurity. The smaller the farm, the greater is the need for marketable surplus and thereby cash income that is essential for sustainable nutrition security. Agricultural productivity trends in recent decades in Africa have been disappointing.

The InterAcademy Council sponsored this study at the request of the Secretary General of the United Nations, Kofi Annan. It was to explore how science and technology can be more effectively used to improve agricultural productivity and thereby to improve food security. This report is complementary to the current assessment by the UN Millennium Development Goals Hunger Task Force as it looks at other aspects involved in reducing hunger and food insecurity.

This report is addressed to a wide audience, ranging in Africa from heads of state, ministers and permanent heads in most portfolios to farmers and their representative organizations. The recommendations and action agenda in the report give a key role to leaders of universities, national agricultural research systems and institutions; the

private sector, regional and subregional intergovernmental organizations; academic, scientific and extension staff; nongovernmental and community-based organizations and the mass media. Multilateral and bilateral financial, research and development and donor agencies are also an important audience, as they have a important role to play in African agricultural development.

Like the first report of the InterAcademy Council in 2004, *Inventing a better future: A strategy for building worldwide capacities in science and technology*, this report is strategic and conceptual rather than prescriptive. This is as intended by the Study Panel. The African continent is large and diverse, and it would be presumptuous of the Study Panel to devise detailed operational plans. These are more appropriately made by relevant national, regional and continental organizations with the knowledge and experience of their mandated domains. The Study Panel hopes that the report's analyses, strategic directions and recommendations will generate a strong sense of ownership and commitment by the various stakeholders in Africa's development, and motivate them to take the necessary next steps.

Toward this objective the Study Panel suggests using pilot programs as a way of connecting its strategy and recommendations. These pilot programs are but one of the five steps that the Study Panel recognizes that are required to realize Africa's agricultural promise and potential:

1. Undertake analyses
2. Formulate strategies
3. Plan and conduct pilot programs
4. Develop operational plans
5. Implement plans.

The Study Panel addresses the first three of these steps; the other two become the next steps for our



readers to embrace and carry forward. To develop a strong sense of ownership and commitment for our intended audience, the Study Panel adopted a two-tiered approach in conducting this study. First, a series of consultative workshops in four regions of Africa were held to allow stakeholders to convey their views on the constraints and opportunities in African agriculture, and the role that science and technology could play in future. Second, several background papers were commissioned on key topics bringing together current thoughts and research for the Study Panel's consideration. The report is hence a synthesis of the outcomes of this two-tiered process, and the result hopefully is a hybrid with vigour.

The Study Panel, composed of 3 Co-Chairs and 15 members, met three times in Africa during 2002-2003 to formulate its recommendations, based on its review of the documentation from the workshops and commissioned papers, extensive electronic communications, and additional papers contributed by the Study Panel members. Strengthened by consultative drafting and spirited redrafting, the report followed the InterAcademy Council's peer review and monitoring processes from December 2003 to February 2004. The final report represents the consensus views of all the Study Panel members.

Speciosa Wandira KAZIBWE
Study Panel Co-Chair

Rudy RABBINGE
Study Panel Co-Chair

M.S. SWAMINATHAN
Study Panel Co-Chair



Report review

This report was externally reviewed in draft form by 13 internationally renowned experts chosen for their diverse perspectives, technical knowledge and geographical representation, in accordance with procedures approved by the IAC Board. The purpose of this independent review was to provide candid and critical comments that would help the IAC to produce a sound report that met the IAC standards for objectivity, evidence and responsiveness to the study charge. The review procedure and draft manuscript remain confidential to protect the integrity of the deliberative process. The IAC wishes to thank the following individuals for their review of this report:

V. BALAJI, Head, Information Resource Management Office, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India

Roger N. BEACHY, President, Donald Danforth Plant Science Center, St. Louis, Missouri, USA

Joachim VON BRAUN, Director General, International Food Policy Research Institute, Washington, DC, United States

Carl N. HODGES, Chairman, Desert Development Foundation, Tucson, Arizona, USA

Monty P. JONES, Executive Secretary, Forum for Agricultural Research in Africa (FARA), Accra, Ghana

Akin MABOGUNJE, Profesor Emeritus, University of Ibadan, and Chairman of Policy Studies Center, Ibadan, Nigeria.

Joseph MUKIIBI, Former Dean, Faculty of Agriculture, Makerere University, Kampala, Uganda

Raj PARODA, Former Director General of Agriculture Research, International Center for Agricultural Research in the Dry Areas –

Central Asia and the Caucasus (ICARDA-CAC)
Regional Office, Tashkent, Uzbekistan

Jim PEACOCK, Research Fellow, CSIRO Plant Industry, Canberra, Australia

Muhammad Abed PEERALLY, Professor of Agricultural Botany, University of Mauritius, Vacoas, Mauritius

Pedro A. SANCHEZ, Director of Tropical Agriculture, The Earth Institute, Columbia University, New York, USA

Emmy SIMONS, Assistant Administrator, Bureau for Economic Growth, U.S. Agency for International Development, Washington, DC, USA

Anne-Lucie RAOULT WACK, Agropolis International, Montpellier, France

Although the reviewers listed above provided many constructive comments and suggestions, they were not asked to endorse the conclusions and recommendations, nor did they see the final draft of the report before its release.

The review of this report was overseen by:

Hans R. HERREN, Director General, International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya

Mamphela A. RAMPHELE, Managing Director for Human Development, The World Bank, Washington, DC, USA

Appointed by the IAC Co-Chairs, these review monitors were responsible for ascertaining that the independent examination of this report was carried out in accordance with IAC procedures and that all review comments were carefully considered. However, responsibility for the final content of this report rests entirely with the authoring Study Panel and the InterAcademy Council.



Acknowledgements

The Study Panel is grateful to the 150 participants in the four consultative workshops held in Africa, for giving of their valuable time and insights. This enabled the identification of the major strategic challenges and opportunities, which the Study Panel found so effective in guiding its deliberations and in drafting this report. These workshops would not have been possible without the willing collaboration of the subregional research organizations, the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA), Le Conseil Ouest et Centre Africain pour la Recherche et le Développement (CORAF), the National Department of Agriculture (NDA) in South Africa and importantly staff of the national agricultural research systems in Africa. The following people from these and other organizations are owed a special debt of gratitude for their assistance with the workshops: Nisreen Al Shawahneh, Mohamed Besri, Sam Chema, Abdelnabi Fardous, Gadi Gumisiriza, Sefu Ketema, Ndiaga M'Baye, Bongeka Mdleleni, Bheki Muchunu, Richard Mkandawire, Keoagile Molapong, Joseph Mukiibi, Hamid Narjisse, Njabulo Nduli, Techalew Negash, Bongiwe Njobe, Marcel Nwalozi, Ramagwai Sebola and Dunstan Spencer. Papa Seck and Monty Jones of the Forum for African Agricultural Research (FARA) and Ian Johnson and Francisco Reifschneider of the Consultative Group on International Agricultural Research (CGIAR) are thanked for allowing a progress report on the study to be presented to meetings of the two organizations.

The Study Panel appreciates the contribution of the authors who prepared background papers, which, together with the consultative workshops, provided the essential building blocks for the report. Those involved were: Nienke Beintema, Prem Bindraban, Carl Eicher, Lawrence Haddad, Peter Hazell, Huub Löffler, David Muduuli, Peter Matlon, Sudip Mitra, Rudy Rabbinge, Han Roseboom Elly Sabiiti, Dunstan Spencer and Clesensio Tizikara.

The Hunger Task Force of the UN Millenium Development Goals program was generous in the provision of data, analyses and maps of the location and extent of malnutrition in Africa. Members of the United Nations and the New Partnership for Africa's Development (NEPAD) both contributed with helpful suggestions and feedback. The Wageningen University and Research Centres in The Netherlands and the International Food Policy Research Institute (IFPRI) provided staff time and information to the Study Panel.

Others who contributed to the Study Panel's deliberations in various ways are also thanked, including Kwaku Agyemang, Alexander Animalu, Stein Bie, Patrick Dugan, Adel El-Beltagy, Willem Jansen, Arie Kuyvenhoven, William Masters, and Meryl Williams. For assistance with writing and editing, the Study Panel expresses its appreciation to Janet Lawrence, Steven Marcus, Sheldon Lippman, Patricia McAdams and Ellen Bouma.

The InterAcademy Council (IAC) secretariat and the Royal Netherlands Academy of Arts and Sciences (KNAW) in Amsterdam, where IAC is headquartered, provided guidance and support for this study. In this regard, special mention is made of the assistance provided by Albert Koers, John Campbell, and Margreet Haverkamp of the IAC Secretariat.

The Study Panel is especially grateful to the Bill and Melinda Gates Foundation, Carnegie Corpora-



tion of New York, and the Netherlands Ministry of Development Cooperation for providing funding to support the study.

Last but by no means least, the Study Panel thanks the InterAcademy Council Board and especially Bruce Alberts and Goverdhan Mehta, the IAC Co-Chairs, for providing it with the opportunity to undertake this important study.



Executive summary

The challenge of African agriculture

Africa is a continent rich in natural and human resources. Africa is a land full of promise and potential, where more than 900 million people live and work and raise their families – two-thirds of them in small towns and villages scattered throughout rain forests, deserts, and immense grasslands that stretch from coast to coast. Yet it is also a place where, because of famine, disease and growing populations, almost 200 million people are undernourished and 33 million children go to sleep malnourished and hungry every night.

How can the best of science and technology be harnessed to help Africa increase its agricultural productivity, profitability and sustainability, thereby contributing to improved food security for all? How, precisely, can we produce higher crop yields and more nutritious foods from thinning soils, making food both affordable and accessible to increasing numbers of people? What are the larger socio-economic and political conditions necessary for the effective use of science and technology in both the public and private sectors?

To answer these questions, United Nations Secretary-General Kofi Annan requested that the Inter-Academy Council (IAC) engage leading scientific, economic, and technological experts from around the world – but primarily from Africa – to identify how best to realize the promise and potential of African agriculture. This report is the result. Written by

the IAC Panel on Agricultural Productivity in Africa, it details a number of concrete steps that the scientific community – working closely with farmers, governments and industry – can take to avert the risk of famine and relieve human suffering for millions of Africans in the years ahead.

The focus of this report is on embracing science and technology not simply to produce a substantial increase in agricultural productivity, but also to ensure that the families of Africa become food secure and obtain the full range of nutrients that they need every day.

Widespread food insecurity exists throughout Africa.

Food security means far more than having sufficient food to meet human needs on a national basis. In fact, food security often has less to do with food availability than with access to food. Access is a hugely elusive and complex problem, a problem complicated not only by low family incomes, but also by lack of roads and the distribution infrastructure needed to move food swiftly from place to place. Other important factors include access to safe drinking water, primary health care and environmental hygiene – all of which play a key role in maintaining good health and reducing the intestinal infections that can negate the benefits of a nutritious diet.

More than 60 percent of malnourished Africans live in Eastern Africa, with more than half of the populations in the Congo Democratic Republic and Mozambique affected. Similarly, Angola, Cameroon, Ethiopia, Kenya, Tanzania and Zambia show malnutrition prevalence rates between 40 and 50 percent.

On the other hand, West Africa as a whole has countered the trend in the rest of the continent, with its malnutrition falling dramatically in recent years. This good news shows that, with a concerted effort, movement away from hunger and an inadequate diet is possible. The nations that have made the progress



are Benin, Ghana and Nigeria. Nigeria's prevalence rate is low, but because of its large population, the country nevertheless accounts for 22 percent of the food impoverished poor in West and Central Africa.

The IAC Panel envisions an African future where increased agricultural productivity, improved food security and an enhanced sustainability of agro-eco-systems can be achieved. Agricultural research and development investments are among the most crucial determinants of agricultural productivity. The near stagnant economies in parts of Africa are, to a large extent, a reflection of a stagnant agriculture. Science and technology can directly contribute to food security not only by the introduction of improved crops and cropping practices, labour-saving technologies, and better communications – but also through an improved quality of food storage, processing, packaging and marketing.

African agriculture has a unique set of features that make it very different from Asia, where the Green Revolution has had a pervasive impact. These include:

- Lack of a dominant farming system on which food security largely depends;
- Predominance of rainfed agriculture as opposed to irrigated agriculture;
- Heterogeneity and diversity of farming systems and the importance of livestock;
- Key roles of women in agriculture and in ensuring household food security;
- Lack of functioning competitive markets;
- Under-investment in agricultural R&D and infrastructure;
- Dominance of weathered soils of poor inherent fertility;
- Lack of conducive economic and political enabling environments;
- Large and growing impact of human health on agriculture;

- Low and stagnant labour productivity and minimal mechanization;
- Predominance of customary land tenure.

In contrast to Asia – where irrigated rice-wheat systems predominate and thus where improved rice and wheat varieties could make a major difference – the diverse African situation implies that no single magic 'technological bullet' is available for radically improving African agriculture. A comprehensive set of strategies will thus be necessary in Africa for the effective harnessing of science and technology to meet human needs. As a consequence, more investment in a wider range of agricultural research and development will be required in Africa than was the case in Asia.

The IAC Panel concludes that African agriculture will require numerous 'rainbow evolutions' that differ in both nature and extent among the many different types of farming systems and institutions throughout Africa – rather than a single Green Revolution.

African farmers pursue a wide range of farming systems that vary both across and within the major agro-ecological zones of Africa. Agro-ecological zones are land regions sharing similar combinations of soil, landform and climatic characteristics. The particular parameters used in the definition of these zones focus attention on the climatic and soil-related requirements of crops and on the management systems under which the crops are grown.

A farming system is a population of crop and livestock enterprises that share similar patterns of farm activities and household livelihoods, including their degree of crop-livestock integration and their scale. Unlike other regions of the world where food production and food security are based primarily on a limited number of farming systems, in Africa these depend on multiple farming systems in a wide array of different agro-ecological zones. Diversity is the



norm in African farming systems throughout the continent. At the level of the individual farm unit, farmers diversify further, typically growing 10 or more crops.

Seventeen distinct farming systems are identified in Africa: maize-mixed, cereal/root crop mixed, root crop, agro-pastoral millet/sorghum, highland perennial, forest based, highland temperate mixed, pastoral, tree crop, commercial-largeholder and smallholder, coastal artisanal fishing, irrigated, rice/tree crop, sparse agriculture (arid), urban based, highland mixed, and rainfed mixed. Most of these African farming systems are characterized by weathered soils of low inherent fertility and high fragility, by a declining soil fertility due to population growth and a minimal use of external inputs, and by highly variable rainfall – especially in the drier rainfed systems. For the foreseeable future, multiple farming systems must become more productive to generate the increases in food necessary to feed the hungry in Africa.

The IAC Panel concludes that, because of the many farming systems used to feed Africa, regionally mediated, rather than continent-wide strategies, will be required to address the diverse problems of African food productivity and food security.

Four farming systems show the most promise for increasing African food security. Given the situation described above, the question arises as to how to determine which farming systems, among so many, could potentially contribute the most to increased agricultural productivity and improved food security in Africa. To answer this question, the IAC Panel has used two main indicators – the extent of malnutrition among children and the economic value of agricultural production – to assess the potential of each African farming system for meeting these goals.

The first indicator reflects the extent of the malnu-

trition that needs to be overcome to achieve food security. The second indicator gauges the potential for agricultural productivity gains to generate increased real incomes for farmers and consumers. The greater the malnutrition, the more the productivity gains will benefit those most in need of improved food and nutrition security. A system is considered a priority system if both the production/ productivity potential and the extent of malnutrition are high.

Based on this analysis, the IAC Panel concludes that the following four African farming systems have the greatest potential for reducing malnutrition and improving agricultural productivity:

- The *maize-mixed system*, based primarily on maize, cotton, cattle, goats, poultry and off-farm work;
- The *cereal/root crop-mixed system*, based primarily on maize, sorghum, millet, cassava, yams, legumes and cattle;
- The *irrigated system*, based primarily on rice, cotton, vegetables, rainfed crops, cattle, and poultry;
- The *tree crop-based system*, based primarily on cocoa, coffee, oil palm, rubber, yams, maize and off-farm work.

Science and technology strategies

A production ecological approach can identify problems and the potential solutions for increasing agricultural productivity in priority farming systems. Science does more than simply breed new crops for farmers to use. Science is also needed to understand what is happening in the fields, making it possible to remedy the problems that arise. For each of the four priority farming systems selected by the IAC Panel, there are many technological opportunities for enhancing productivity and profitability on an environmentally sustainable basis. A production ecological approach examines the factors defining, limiting and reducing crop yield, as well as those



that interrupt the distribution of foods after they have been grown. This approach allows for a comprehensive identification and prioritizing of agro-ecological constraints, thereby identifying the most promising technological opportunities for improvement.

These opportunities can be categorized according to their effects on four classes of factors:

1. *Growth- and yield-defining factors (genetic potential, climate and weather)*: High-yielding varieties of many different crops are commonly grown throughout the world. These varieties have been the key to a dramatic increase in yield. In the past, for example, high-yield wheat and rice formed the heart of the Green Revolution in Asia. Given the diversity of production environments and farming systems in Africa, crop improvement research needs to use approaches that develop new varieties with a genetic potential specifically suited to local niches, placing a premium on participation and feedback from farmers.
2. *Growth- and yield-limiting factors (water availability, plant nutrition, soil fertility and labour)*: Crop growth and yield are limited by poor plant nutrition and uncertain water availability during the growing cycle. Depletion of soil fertility, in fact, is a major biophysical cause of the low per capita food production in Africa. This loss of nutrients can be counteracted by the application of appropriate fertilizers. Thus, research should be directed at understanding and resolving the factors that limit access to fertilizers, as well as those that can make fertilizer use more efficient. In addition, research is needed on the factors that can make irrigation more accessible and less costly for small farmers – and on techniques for improving integrated soil, water and nutrient management.
3. *Growth- and yield-reducing factors (weeds, pests, diseases and pollutants)*: Pests, diseases and weeds are

a huge problem in nearly all farming systems around the world. Africa is no different. Cassava Mosaic Disease, for example, can completely destroy a crop in heavily infected areas. Whereas the possibilities for chemical control of pests and diseases are restricted because of limited availability and cost of pesticides, farmers find resistant varieties of plants to be a powerful tool whenever the appropriate varieties are available. Technology-driven options require the development of varieties with properties such as salt tolerance and resistance to the prevailing pests and diseases. Here, biological pest controls can offer a number of excellent alternatives to chemical control. Genes conferring resistance to pests and diseases have been transferred to certain target crops from a wide range of sources, far exceeding the biological constraints of conventional plant breeding. Although such biological pest control techniques reflect powerful alternatives to chemical pesticides and herbicides, these technologies have not yet been effectively applied to most African challenges.

4. *Post-harvest losses that reduce the distribution of foods to the marketplace*: Much of the food produced in Africa is lost in post-harvest processes. Some studies report staggering losses, ranging in some countries from 10 to 100 percent. Sweet potato, plantain, tomatoes, bananas and citrus fruit, for example, often perish before reaching the market. A reduction of this wastage would benefit growers and consumers alike. Local processing plants established throughout the African countryside could provide a critical solution to this problem. Local agro-processing not only restricts post-harvest losses; it also increases the economic value of harvested agricultural products. A policy oriented towards such development would produce much more innovation in food processing and distribution in Africa.



The IAC Panel concludes that, in harnessing science to increase the productivity of African agriculture, the application of a production ecological approach will be critical for identifying both problems and their potential solutions.

The correct and diligent application of a range of technology options can increase crop and animal production, while making more effective and efficient use of land, labour and capital. Improving agricultural productivity and food security in Africa will require a number of different approaches. These range from production developments focused on removing constraints in priority farming systems, to yield gap analyses for many of Africa's crops, to an emphasis on the mechanisms for adapting technologies to farmers' needs.

The IAC Panel is encouraged by the availability of technology options and the experience with their application in some African farming systems. There are ample opportunities to bridge yield gaps and increase productivity. But to do this will require a systematic fine-tuning of the technology options to improve adoption.

There are many documented examples of successful productivity-enhancing innovations. The challenges are both to scale them up and to develop new options for the future. For example, African agriculture should derive maximum benefit from both conventional plant breeding and biotechnology. Rapid developments in information and communication technologies – such as the Internet, the World Wide Web, and cellular telephones – also provide important new opportunities for improving agricultural productivity and food security in Africa. Information technology has also stimulated the development of comprehensive computation models, such as models of crop and animal growth. New mapping technologies provide important information for African

farmers, scientists, and policy makers. Tools such as geographic information systems (GIS), global positioning system (GPS) and thematic maps of seasonal movements of livestock reinforce the identification of relevant know-how. Such mapping techniques, for example, can help to identify land boundaries, establishing the land ownership or tenure necessary for obtaining credit for agricultural investments.

The IAC Panel suggests the desirability of establishing African centres of agricultural research excellence (ACARE) to undertake basic research leading to the development and use of these and other novel new technologies for improving African agriculture. Such centres should be designed to provide a source of new ideas and methods for national agricultural research systems.

It must be emphasized that the application of science and technology alone will not have a significant impact on improving productivity or on reducing the numbers of food insecure. There are complementary investments and policies that will also be required to achieve sustainable productivity growth and reduce food and nutrition insecurity. These include fair, competitive and efficient markets, revitalization of the private sector, improved governance, investments in sanitation, drinking water and health services, and broad policy and institutional innovation to create the enabling conditions for science and technology to express their potential at local, national, regional and global levels.

The IAC Panel recommends the following actions for improving agricultural productivity and food security in Africa through science and technology strategies:

Near-term impact

- *Adopt a production ecological approach with a primary focus on the four identified continental*



priority farming systems. These priority farming systems represent agricultural bright spots, in as much as the increased agricultural productivity anticipated will improve the welfare of large numbers of food insecure people.

- *Pursue a strategy of integrated sustainable intensification.* The aim of science and technology should be to produce integrated soil, water, nutrient, and pest management approaches that are effective for African farmers. Knowledge-intensive and technology-driven approaches must be integrated with indigenous knowledge and farmers' needs and demands to ensure the appropriateness and adoption of these innovations.
- *Adopt a market-led productivity improvement strategy to strengthen the competitive ability of smallholder farmers.* Farmers should be able to respond effectively to price signals in the marketplace, aided by information and communications technology. This will help achieve a balance between supply and demand and provide incentives for farmers to close existing yield gaps, allowing them to become more income secure in the process.
- *Reduce land degradation and replenish soil fertility.* Soil health and fertility management holds the key to enhancing crop productivity in Africa. An integrated approach that includes exploiting the effects of both inorganic and organic fertilizers on soil, water and crop productivity can break the downward spiral of land degradation.
- *Recognize the potential of rainfed agriculture and accord it priority.* Because the possibilities for economically viable and environmentally benign irrigation development in Africa are limited, rainfed agriculture will remain the dominant system for decades to come. This type of farming, therefore, offers the best opportunities for the improved productivity that reduces poverty and food insecurity.
- *Explore higher-scale integrated catchment strategies for*

natural resource management. The projected water scarcities in many regions of Africa require strategies and policies for its sustainable use to address the increasingly competitive multi-sectoral demands for water. These strategies should be explored to optimize land and water use to safeguard biodiversity, manage forest resources, and conserve native vegetation and wildlife habitat.

- *Enhance the use of mechanical power.* Encourage the local manufacture of agricultural machinery and equipment for all phases of agricultural production so as to enhance development and reduce the African countries' dependence for such goods on the industrialized countries of the world.
- *Embrace information and communication technology at all levels.* Vastly improved access to information and communications technology is essential to realize these opportunities and to reach the isolated and excluded villages of Africa.

Intermediate-term impact

- *Bridge the genetic divide.* A substantial amount of additional investment is needed to respond to the specific needs of African farmers if they are to derive benefit from the integrated application of both conventional breeding techniques and biotechnology. Africa cannot rely on external developments in this field. Biotechnology has a significant gestation period before its impact is realized. Without substantial investments now – including by the private sector – Africa will be left behind. The full range of biotechnology components, including the appropriate use of genetically modified organisms, needs immediate attention to help improve eco-farming.
- *Improve the coping strategies of farmers in response to environmental variability and climate change.* The severe constraints in African agriculture include a high risk of crop failure and animal death because



of the variability in weather, particularly rainfall. Climate change highlights the necessity to develop anticipatory short- and long-term forecasting research, and this requires the training of scientists.

Long-term impact

- *Promote the conservation, sustainability and equitable use of biodiversity.* Africa has a rich treasure trove of biodiversity in flora and fauna. In many circumstances, properly structured private-public sector partnerships can provide a means of exploiting this potential through the creation of niche markets. A market in medicinal plants is one possibility. Conservation and commercialization strategies must be mutually reinforcing, so as to create an economic stake in conservation.

Institution building

More effective institutions in Africa are required to improve agricultural productivity and food security.

As emphasized and explained in the first report from the InterAcademy Council, *Inventing a better future: A strategy for building worldwide capacities in science and technology*, ‘science and engineering advance largely at ‘centers of excellence’ – physical locations where research and advanced training are carried out, often in collaboration with other centers, institutions, and individuals. Centers of excellence are the key to innovation, and their importance cannot be overestimated. For the science and technology capacities of developing countries to grow, therefore, they too should have centers of excellence – whether of local, national, regional, or international status. These centers of excellence do not necessarily have to be created *de novo*. The bolstering or reform of a country’s most promising existing R&D programs can achieve the desired outcome. A key to promoting excellence is a merit-based allocation of resources based on rigorous review, both in deciding on new

research projects and evaluating current programs. Given the relatively modest scientific capacity of most developing nations, such reviews should ideally include appropriate experts from other nations.’

Scientific and technological institutions in Africa are predominantly public, with the private sector playing a minimal role until now. The national agricultural research systems in Africa have been undergoing reforms to make them more responsive and effective. Institutional innovations designed to strengthen these systems currently are being explored.

The IAC Panel examined the current status of agricultural research and development institutions throughout Africa, and it has attempted to evaluate the various trends in their evolution and to diagnose the challenges they face. A number of strategies and priorities are desirable from the international level down to the local level. The IAC Panel noted that one of the greatest challenges is the need to make agricultural research more client oriented and client driven through the participation of farmers and other stakeholders, at the same time struggling with the realities that, among the poorest farmers – subsistence farmers, for example – such involvement is unlikely to come soon. However, all agricultural research institutions, whether based in universities or in independent centres, must develop close working relationships with farmers to create the feedback mechanisms that are essential for analyzing problems and finding appropriate solutions.

At the subregional level, Africa needs more effective agricultural research networking that defines a common research agenda, shares research tasks according to institutional comparative advantage and ensures efficient and equitable sharing of research results across participating countries. Where there are priority research gaps and/or where there would be major efficiency gains by grouping resources in-



stitutionally, African centres of agricultural research excellence should be created to address strategic continental, regional and sub-regional priorities. Wherever possible, these centres of agricultural research excellence should evolve from and build upon existing national agricultural research systems, international agricultural research centres and university programs, rather than creating another layer of institutions.

International agricultural research centres (IARCS) with headquarters and/or programs in Africa should retain their international identities, but operate in more collaborative and complementary modes with national agricultural research systems and universities in Africa, as well as in participatory partnerships with farmers, consumers and the private sector. They should immediately integrate their programs at the operational level in consortia within specific agro-ecological regions. In this manner, they will be more responsive to African priorities and ensure a critical mass of research personnel to exploit economies and synergies. Strategies to achieve such full institutional integration should be explored by the Consultative Group on International Agricultural Research (CGIAR) as a matter of priority.

Agricultural extension services that link timely agricultural research directly to farmers is currently moribund in many African nations. Kenya, for example, has 12,000 extension agents, but no funds to buy petrol for motorbikes. There is a need for more research on the future of extension systems in Africa. The new International Service for National Agricultural Research Division of the International Food Policy Research Institute (IFPRI) can be especially helpful in designing best practice options for the future.

The IAC Panel believes that Africa deserves a dramatic and sustained increase in the resources devoted to agricultural research and development. Higher

salaries are needed for scientists. That said, however, good scientists value other aspects of their work in addition to competitive salaries. Social prestige and recognition, for example, and a working atmosphere in an institution that values merit and innovation are equally important. Above all, impact-oriented research organizations need visionary leaders to inspire and nurture their team to achieve great goals.

Nurturing good scientists through merit-based selection systems that create and maintain strong, quality institutions must become one of the highest priorities of governments, if they are to bring the benefits of modern science and technology to their farming and rural communities. Unless the above features are built into the design of a national agricultural research system, its impact will be low and it will neither attract nor retain gifted scientists.

The IAC Panel recommends the following actions for building impact-oriented research, knowledge and development institutions:

Near-term impact

- *Design and invest in national agricultural science systems that involve farmers in education, research and extension.* In place of the outmoded linear and top-down research-extension-farmer framework that has failed in Africa, design new innovation, information, knowledge and education systems – with new information and communications technologies playing a central role. Start from the bottom up in developing rural knowledge-based systems using participatory models.
- *Encourage institutions to articulate science and technology strategies and policies.* To maximize the benefits and achieve true food security, a coordinated strategy is needed that includes not only agriculture, but also health, education, and rural planning



and development. There is a special need to recognize the key role of women's education and status in reducing child malnutrition – the most insidious form of malnutrition so prevalent in Africa.

- *Increase support for agricultural research and development.* Africa's agricultural science community cannot flourish if it continues to depend upon foreign aid for approximately 40 percent of its budget. Governments as well as donor agencies must recognize that building impact-oriented institutions requires sustained and sizable increases in the support of agricultural research and development. To decrease the dependency on foreign aid, more investment is needed by Africa itself. Agricultural research funding in Africa should increase in real terms by at least 10 percent per year to 2015. This would double the agricultural research investment on average to at least 1.5 percent of agricultural GDP in African nations.

Intermediate-term impact

- *Cultivate African centres of agricultural research excellence.* These centres (ACARE) should be designed to enable research on both continental and regional priorities as a complement to the national agricultural systems. By using modern communication technologies to network with other institutions with complementary skills and goals, each centre will become a virtual centre for particular research areas. Each would be African owned and governed, thereby providing a magnet for African scientists to remain at home, as they work to strengthen African national agricultural research systems. National academies of sciences in Africa and other nations (through the InterAcademy Panel on International Issues and the InterAcademy Council) should play a role in identifying suitable candidate research institutions that could become

centres of agricultural research excellence.

- *Strengthen international agricultural research centres.* International agricultural research centres with headquarters and programs in Africa should retain their international identities. They should, however, operate in more collaborative and complementary modes with national agricultural research institutes and universities, and in participatory partnerships with both farmers and consumers. The level of investment in the CGIAR African centre programs for research and capacity building should be increased by 5 per cent per year, to at least US\$235 million by 2015.

Producing new agricultural scientists

African nations must create and retain a new generation of agricultural scientists. Great strides have been made in increasing the number of universities in Africa and the number of students enrolled. Universities throughout the continent, however, are facing severe financial problems, coupled with a decline in the quality of the educational experience. At the same time, many senior academics are leaving the university to go into the private sector or to attractive international positions. This brain drain has crippled many African universities that are urgently struggling to build master's and doctoral programs. Senior scholars are needed desperately in the halls of academia.

Meanwhile, out in the field, the first generation of African agriculturalists has retired and their successors are becoming demoralized by the poor conditions of service and the low return rate from overseas of many young academics.

At the primary and secondary school levels, science education is given little emphasis and education is weak. Most schools lack even rudimentary libraries and science laboratories, not to mention



teachers who know enough about science to teach it well. And access to computers is minimal. Few secondary school graduates go on to the universities to train in the sciences, and those who do are poorly prepared. Women are discouraged from becoming scientists, especially agricultural scientists.

Science education, in short, is a huge problem in Africa. African governments, with support from development partners, must pursue strategies that create incentives and opportunities for scientists to stay and work in their countries. They must also invest more in science and technology at all levels of education, so as to create an attractive environment and demand for further science and technology education. Incentive and reward systems should encourage innovation and entrepreneurship in the agricultural sector.

The private sector must contribute to agricultural research and support higher education. The curriculum must be flexible, market driven and more holistic, incorporating aspects of sensitivity to the environment and sustainability, natural and social science, information technology and entrepreneurship. It must produce scientists with commitment to lifelong learning.

The IAC Panel recommends the following actions for creating and retaining a new generation of agricultural scientists:

Near-term impact

- *Broaden and deepen political support for agricultural science.* Real improvement in agricultural education and research requires strong support from top political leaders. A coalition of supportive agricultural constituencies must be formed, including farmers associations, producer groups, national agribusiness companies, educators and researchers.

- *Mobilize increased and sustainable funding for higher education in science and technology, minimizing dependence on donor support.* There is an urgent need for an increase in both the numbers of students and the quality of their agricultural education (e.g., science, food processing, natural resource management, and rural development) at primary, secondary and tertiary levels. At the tertiary level, the ‘sandwich model’ provides an effective tool for building capacity while maintaining a focus on African needs. This model educational approach allows university students in developing nations to spend one year at a university in an advanced s&t nation, then return to their home universities for completion of their degree programs.

Intermediate-term impact

- *Focus on current and future generations of agricultural scientists.* A greater effort must be made to retain current and future generations of African scientists to reduce the brain drain. This requires the implementation of policies that create personally and professionally rewarding scientific opportunities in Africa. Such policies must include merit-based selections and promotions, competitive compensation, well-equipped laboratories, access to global sources of scientific information, and adequate operating funds.

Long-term impact

- *Reform university curricula.* The undergraduate curricula of agricultural universities should stress production ecological and multi-disciplinary approaches to better prepare scientists for the new innovation, information, knowledge and education systems. Students should be directly exposed to farmers’ needs and to quality agricultural research and extension (completing the synergistic ‘quad-



range' recommended in this report). They should also become better sensitized to the socio-economic and policy environments in which agricultural development occurs and in which they will be working during their careers.

- Strengthen science education at primary and secondary school levels. A special emphasis must be placed on improving the accessibility and friendliness of science training to young women. Farm science schools where the pedagogic methodology is 'learning by doing' are urgently needed for the knowledge and skill empowerment of farmers.

Enhancing markets

A vibrant market economy and effective economic policies are essential in making poor families income and food secure. If a market-driven agricultural productivity recovery is to be successful, improved governance, market access, information, communications, and transport will be vital complements to the science and technology thus far described. Creating an effective policy environment – one that is capable of exploiting the potential that science and technology offer – will require innovative ways to engage small farmers so that they become better informed and more active participants in markets, policy processes, and priority setting in agricultural research and development.

African countries need an increased capability to address product quality and to comply with bio-safety standards and other regulatory regimes. They also need the skills to negotiate effectively with the member nations of the Organization for Economic Co-operation and Development (OECD). Only then will the private sector express its unrealized potential to contribute to the agricultural productivity recovery.

Governments need to increase investments in infrastructure such as roads, information and commu-

nications technologies, storage, and post-harvest technologies. Appropriate grading standards for agricultural products, as well as sufficient sanitary and phytosanitary regulations, must be in place and enforced. Unless this is done, the private sector will continue to languish. Regional cooperation is required to remove formal and informal barriers to trade, strengthen the contract system, establish food quality and food safety standards and regulations, and increase research capacity in all these areas. Such cooperation can promote interregional trade within Africa and widen international market opportunities, which can provide a floor to commodity prices as agricultural productivity and marketable surpluses increase. National, regional, continental, and international markets should be competitive, free and fair for African farmers and consumers.

There is a need in Africa to institute appropriate intellectual property systems that optimize access to external intellectual property and incentives to attract foreign investment, while creating and protecting both incentives for local innovation and the value of local resources.

The IAC Panel recommends the following actions for enhancing the role of markets and policies in making poor families income and food secure:

Near-term impact

- *Increase investments in rural infrastructure.* Governments must increase investments in roads, information and communications technology, storage and post-harvest technology, and ensure that appropriate standards and regulations are in place and enforced.
- *Strengthen capacity to expand market opportunities.* Regional cooperation is required to remove formal and informal barriers to trade, strengthen the con-



tract system, establish food quality and food safety standards, and increase research capacity in all these areas.

- *Reduce barriers to increased African trade with OECD countries.* Improved international market access will be a key ingredient in translating increases in African agricultural productivity into improved food security. OECD countries should assist developing countries in meeting quality and safety standards and in helping to improve their decision-making abilities through collaborative research.
- *Improve data generation and analysis related to agriculture, food, and nutrition security and vulnerability.* Without good data, there are major constraints to the analysis of productivity trends and the design of appropriate strategies and policies for science and technology. The U.N. Food and Agriculture Organization, with the World Health Organization and UNICEF, should take the leadership in this endeavour and design strategies to ensure that in the future, the needed data are free of political influences.

Intermediate-term impact

- *Institute effective intellectual property rights regimes to encourage the private sector and facilitate public-private partnerships.* If the benefits of modern science and technology are to reach small African farmers, it will be important to pay attention to issues of intellectual property rights. Resource-poor farmers will be excluded from the benefits of modern science, including biotechnology, if measures are not taken to avoid social exclusion in the dissemination of new technologies.

New science and technology pilot programs

The choices identified in the four strategic themes described above have to be implemented and made operational in the various regions of Africa. To demonstrate the required activities of the various stakeholders in the regions, innovative new participatory science and technology pilot programs should be introduced in each of the four priority farming systems identified by the IAC Panel. Many technological opportunities exist for enhancing productivity and profitability on a sustainable basis. Enhancing productivity in these systems will reap positive consequences in improving the nutrition of a high percentage of starving children, including those who are among the most malnourished on the continent.

The IAC Panel believes that a set of such pilot programs will be needed to unleash the latent agricultural productivity in Africa, leading to an enhancement of family food supply and income security. These experimental programs can serve as inspiring illustrations of the potential of the African agriculture system. The United Nations Secretary-General, in consultation with the African Union, should identify the most appropriate regional, national and international institutions to implement the recommended innovative science and technology pilot programs, which are designed to shape Africa's agricultural future. It is crucial that there be strong African involvement at every step.

The IAC Panel recommends the following action for initiating a series of innovative pilot programs for enhancing African agriculture:

- *Employ the IAC Panel's recommended strategies to implement a series of Participatory Science and Technology Pilot Programs.* Within the pilot schemes, plans should be developed that stimulate convergence



and synergy among the range of programs designed to achieve the following United Nations Millennium Development Goals:

1. Eradicate extreme poverty and hunger through a shift from unskilled to skilled work and through sustainable farming system intensification, diversification and value-addition.
 2. Achieve universal primary education.
 3. Promote gender equality and empower the technical training of women.
 4. Improve maternal health and nutrition to avoid the birth of low-weight babies.
 5. Combat HIV/AIDS, malaria, and other diseases.
 6. Ensure conservation and the enhancement of basic life-support systems including land, water, forests, biodiversity and the atmosphere.
- *Science and technology pilot programs should be introduced where the following components of the production–processing–marketing–consumption chain can be developed in a participatory mode:*
 1. An assessment of indigenous technology options relevant to improvement of productivity and food security.
 2. An assessment of market potentials and constraints for existing and prospective commodities in the farming systems.
 3. An assessment of the scope for the following new technology options to enhance productivity and food security:
 - Integrated nutrient and soil fertility enhancement;
 - Integrated pest management;
 - Small-scale water harvesting and efficient and economic use through micro-irrigation systems of delivery of water and nutrients;
 - Biotechnological applications like improved genetic strains (including genetically modified organisms, where relevant), biofertilizers and pesticides;
 - Use of improved farm implements and appropriate mechanization for increasing labour productivity, reducing drudgery and ensuring timely farm operations;
 - Introduction of appropriated post-harvest processing, storage and marketing techniques;
 - Promotion of non-farm employment through the introduction of technology options for adding economic value to primary products and through agri-business enterprises based on micro-credit;
 - An information and communication program to provide location-specific information relating to meteorological, management and marketing factors and to promote genetic, quality and trade literacy among smallholder rural farm families;
 - Establishment of farmer field schools for integrated pest, disease and weed management; integrated water and fertility management; and the other aspects of production and post-harvest technologies based on the principle of learning-by-doing;
 - Promotion of institutional structures like cooperatives and self-help groups that can confer the power of scale to smallholders at the production and post-harvest phases of farm operations.
- *For each pilot program, explore the scope for other institutional innovations such as:*
 1. Promotion of a participatory knowledge quadrangle coalition led by smallholders and involving them with universities, national agricultural research institutions and extension agencies to explore new modes of partnership.
 2. Identification of candidates for African centres of agricultural research excellence (ACARE) that would serve the interests of smallholders.
 3. Stimulation of public-private partnerships that



would address priority constraints that cannot be alleviated by independent activities and that are aimed at building trust and synergies.

4. Identification of the constraints at the national, regional, continental and global levels that can prevent the realization of the promise and potential of the Participatory Science and Technology Pilot Programs to improve agricultural productivity and food security at the local level.

The IAC Panel suggests that interdisciplinary teams from the quadrangle of national agricultural research systems, universities, extension services and farmers' organizations be constituted to prepare business plans for policy changes and research in each of the four priority farming systems described previously. Nothing succeeds like success, and hence the sites for the initial pilot programs should be developed where there is a socioeconomic, political, scientific and ecological environment conducive to the achievement of the goals of this program. For each pilot program, a local farmers' advisory council, involving both men and women, should be constituted to assume ownership and undertake monitoring and evaluation.

The promise and potential of African agriculture

The IAC Panel affirms its vision of an African future where increased agricultural productivity, improved food security and enhanced sustainability of agro-ecosystems will have been realized. The IAC Panel cautions, however, that this vision is achievable only by effective collaboration among the scientific community, farmers, governments, nongovernmental organizations, the international donor community and the private sector.

Five underlying strategic themes should guide the future of agricultural research and development in Africa towards 2015. The first theme is the identification of science and technology options that can make a difference. The full complement of available technologies should be explored, from conventionally bred plants to genetically modified plants, from chemical fertilizers to organic fertilizers, and from integrated pest, soil and nutrient management to irrigation. A second theme to guide the future is to build impact-oriented research, knowledge and development institutions that reflect the needs of the local farmers in identifying new avenues of research. This goal is best accomplished by involving farmers, who very clearly understand the problems. The third theme is creating and retaining a new generation of agricultural scientists to perform future research. The fourth theme is ensuring markets and policies that make the poor prosperous and food secure. The final theme is the need for experimentation in creating effective solutions to the problems of African agriculture, especially those that empower the farmers in Africa to make decisions about their own crops and their own livelihoods.



1. Introduction

In Africa millions hover near starvation in a world of plenty. Since 1990, food availability per capita in Sub-Saharan Africa has declined by 3 percent. This compares to per capita increases of more than 30 percent in Asia and 20 percent in Latin America. Almost 200 million Africans were undernourished at the dawn of the millennium compared to 133 million in 1980. Currently 33 percent of Sub-Saharan Africans and 6 percent of North Africans are undernourished. Children undernourished in Africa now number 33 million, or more than one-third of pre-school children. Almost all of these children live in Sub-Saharan Africa, the only region in the developing world where child undernourishment has been increasing.

In March 2002, United Nations Secretary-General Kofi Annan requested the InterAcademy Council (IAC) to undertake a study and develop a strategic plan by which the best of science and technology (s&t) could be harnessed to help Africa substantially increase its agricultural productivity, thereby contributing to improved food security. The Secretary-General asked the IAC to engage leading scientific, economic and technological experts in the exercise. His letter to IAC is reproduced in Box 1.1.

The InterAcademy Council appointed the Study Panel on Agricultural Productivity in Africa; 11 of its 18 members were from developing countries, 7 of whom were from Africa. Study Panel members were nominated by their respective country's academy of science through the auspices of the InterAcademy Panel on International Issues (IAP) and approved by the IAC Board. As requested by the UN Secretary-General, the report with its findings and recommendations addresses a wide community – primarily the peoples and governments of Africa – including African heads of state; ministers (of science and technology, agriculture, fisheries, forestry, livestock, finance, education and water); executive officers of international agricultural research and development agencies, international and African regional financial institutions, African national agricultural research systems, educational institutions, and the private sector; leadership of African subregional organizations, the Forum for Agricultural Research in Africa and the New Partnership for African Development (NEPAD); OECD country ministries of trade, commerce, treasury, and international cooperation; and the farmers, scientists, educators and extensionists in Africa.



Box 1.1 Letter from the Secretary-General of the United Nations





The study process

The Study Panel met on three occasions – in Kampala, Uganda (September 2002), Alexandria, Egypt (March 2003) and Stellenbosch, South Africa (June 2003) – and interacted continuously throughout the drafting and reviewing of the report via electronic communications.

After the Kampala meeting, the Study Panel conducted a series of joint consultative African regional workshops (January and February 2003) in association with subregional organizations. The subregional organizations were responsible for agricultural research coordination in three of the four regions of Africa. The Southern Africa workshop was organized jointly with the National Department of Agriculture of South Africa. Summary proceedings of these four workshops are accessible from the IAC website, www.interacademycouncil.net. Sponsors, dates, location, and participant numbers for the four workshops are as follow:

- Eastern and Central Africa (Association for Strengthening Agricultural Research in Eastern and Central Africa/InterAcademy Council (ASARECA/IAC)), 31 January-2 February 2003, Inter-Continental Hotel Nairobi, Kenya; 43 participants (Omoro and Sheikh, 2004).
- Northern Africa (Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA)/IAC), 3-5 February 2003, Hassan II Institute of Agronomy and Veterinary Medicine, Rabat, Morocco; 30 participants (Besri, 2004).
- Southern Africa (National Department of Agriculture, Republic of South Africa/IAC), 7-9 February 2003, Magaliesburg, South Africa; 32 participants (Anandajayasekeram and Sebola, 2004).
- Western and Central Africa (Le Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles (CORAF)/IAC), 10-12 February 2003, Dakar, Senegal; 45 participants (Spencer, 2004).

The aims of the workshops were twofold: (1) understand the regional constraints to improved agricultural productivity as a means of improving food security; and (2) identify explicitly the role of science and technology in alleviating constraints and exploiting opportunities.

The 150 participants in these workshops, the vast majority of whom were African scientists and policy makers, showed great interest in and commitment to the IAC study. They viewed the study as timely in the light of the renewed interest being accorded to agriculture, and more particularly to the role science and technology could play in its advance. The consultative workshops provided the Study Panel with some consistent messages about



the main challenges and opportunities in science and technology on the continent. These were organized topically by (a) institutional issues; (b) policy environment and (c) science and technology strategies. The Study Panel discussed these at length in their deliberations. The priority issues that emerged from the consultative workshops are summarized in Annex A.

The Study Panel Co-Chairs and some Study Panel members also attended meetings of the Consultative Group on International Agricultural Research (CGIAR) Executive Committee and the Forum for Agricultural Research in Africa (FARA), as part of the consultative process. A Progress Report was presented at these meetings and comments and suggestions encouraged. The Progress Report was also shared with the 150 or so workshop participants.

Several background resource papers were commissioned by the Study Panel to complement the consultative workshops. Their purpose was to review the literature on subjects that the Study Panel felt was integral to the study. They covered the following topics:

- African agricultural systems and their productivity: trends, constraints and opportunities (Spencer, Löffler and Matlon, 2004);
- Constraints and opportunities in science and technology for Africa (Bindraban and Rabbinge, 2004);
- The status and potentials in African s&t institutions (Roseboom, Beintema and Mitra, 2004);
- Mobilizing and motivating the next generation of African scientists (Eicher, 2004)

These background papers are also accessible on the IAC website.

Scope of the study

As it approached its task, the Study Panel was conscious that there are many determinants of food security. Thus the focus on science and technology was kept well to the fore in defining the scope of the study at the Kampala meeting. It was agreed that the study would acknowledge the following elements:

- A continental approach that includes all of Africa;
- A consideration of crops and livestock, inland fisheries, aquaculture, and agro-forestry;
- An understanding of the challenge that recognizes agricultural factor productivity as a means to achieve sustainable food security, not as an end in itself;



- A primary focus on food commodity productivity, with recognition that commercial, non-food commodity productivity is also relevant to food security;
- A focus on both pre- and post-harvest productivity;
- A broad definition of science and technology that includes not only agricultural sciences but also related disciplines such as information and communication technologies, geographic information systems, energy, and others insofar as they influence agricultural productivity;
- A consideration of policies that affect agricultural productivity, including those related to science and technology, agriculture, macro-economics and trade;
- Sectors other than agriculture, such as health and education, would only be addressed insofar as they affected agricultural productivity – the impact of HIV/AIDS on scientific capacity and farm labour supply is but one example;
- An emphasis on bottom-up approaches to the formulation of strategies and priorities and an institutional overview that includes horizontal and vertical dimensions of the policy and institutional environments;
- An agricultural/farming/production systems approach that goes beyond cropping systems.

The focus of the report is on science and technology and the enabling environment required for science and technology to impact on productivity, profitability, sustainability and food security. It has not addressed the factors such as conflicts and other shocks which can prevent science and technology from properly expressing its full potential, although their importance is acknowledged. The Study Panel notes that while there are many countries in Africa where such conflicts and natural calamities have led to food insecurity, there are examples where food insecurity persists even though there have been no conflicts or calamities. The report also focuses only on s&t applications to improve agricultural productivity and thus the availability, affordability and accessibility of food supplies. It does not address interventions to improve access to clean water, health services and female education that are critically important complements to achieve food and nutritional security.

African smallholders are central to the report, as it is here that the real productivity and food security challenges for science and technology exist. Special efforts are needed to improve the productivity of resource-poor farmers, to help them increase their marketable surplus and thereby generate additional cash incomes. The overriding majority of African agricul-



turists will in the next decade still be on small holdings with mixed cropping systems often involving livestock. However, large commercial farming will also feature where appropriate, to generate broader economic growth of African countries.

Structure of the report

At its second meeting in Alexandria, the Study Panel agreed on the major issues to be addressed in the report. These are explored in Chapter 2, Food security in Africa; Chapter 3, African agricultural production systems and productivity in perspective; Chapter 4, Science and technology options that can make a difference; Chapter 5, Building impact-oriented research, knowledge and development institutions; Chapter 6, Creating and retaining a new generation of agricultural scientists; and Chapter 7, Markets and policies to make the poor income and food secure. In the final Chapter 8, the Study Panel has drawn together strategic recommendations and action agendas that respond to these issues under five major strategic themes. Together these represent an operational strategy for science and technology in Africa, aimed at improving agricultural productivity and food security. The relevant recommendations for each of the target audiences are identified in Annex B.



References

- Anandajayasekaram, P. and R. J. Sebola. 2004. Summary, Conclusions, and Recommendations: Southern Africa Workshop on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in Southern Africa. Magaliesberg, North West Province, Republic of South Africa, February 7-9, 2003. National Department of Agriculture, Republic of South Africa and InterAcademy Council. Accessible at www.interacademycouncil.net
- Besri, M. 2004. Summary, Conclusions, and Recommendations: North Africa Workshop on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in North Africa. Rabat, Morocco, February 3-5, 2003. Hassan II Institute of Agronomy and Veterinary Medicine (IAV HASSAN II), Association of Agricultural Research Institutions in the Near East and North Africa and InterAcademy Council. Accessible at www.interacademycouncil.net
- Bindraban, P. S. and R. Rabbinge. 2004. Technologies That Can Make a Difference: Enhancing Agricultural Productivity in Africa. Background Paper No. 2 commissioned by the InterAcademy Council (IAC) Study Panel on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in Africa. InterAcademy Council. Accessible at www.interacademycouncil.net
- Eicher, C. K. 2004. Rebuilding Africa's Scientific Capacity in Food and Agriculture. Background Paper No. 4 commissioned by the InterAcademy Council (IAC) Study Panel on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in Africa. InterAcademy Council. Accessible at www.interacademycouncil.net
- Omoro, A., and D. Sheikh. 2004. Abstracts of Presentations and Synthesis of Discussions: Workshop for Eastern and Central Africa on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in Eastern and Central Africa. Nairobi, Kenya January 31-February 2, 2003, Association for Strengthening Agricultural Research in Eastern and Central Africa and InterAcademy Council. Accessible at www.interacademycouncil.net
- Roseboom, J., N. Beintema, and S. Mitra. 2004. Building Impact-Oriented R&D Institutions. Background Paper No. 3 commissioned by the Inter-Academy Council (IAC) Study Panel on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in Africa. InterAcademy Council. Accessible at www.interacademycouncil.net
- Spencer, D. 2004. Summary Report CORAF/IAC Consultation Workshop on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in West and Central Africa (WCA). Dakar, Senegal, February 10-12, 2003. Le Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles and InterAcademy Council. Accessible at www.interacademycouncil.net
- Spencer, D.S.C., P. J. Matlon, and H. Löffler. 2004. African Agricultural Production and Productivity in Perspective. Background Paper No.1 commissioned by the InterAcademy Council (IAC) Study Panel on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in Africa. InterAcademy Council. Accessible at www.interacademycouncil.net



2. Food security in Africa

The United Nations Food and Agriculture Organization (FAO) has estimated that almost 200 million Africans were undernourished at the dawn of the millennium, compared with 133 million 20 years earlier (FAO, 2000: 20). The rate of increase in undernourishment in Africa vastly exceeds that of other developing regions.

Yet West Africa has gone against the trend in the rest of Africa, with its numbers and the prevalence of undernourishment falling dramatically over the period, and this is reason for optimism that trends can be reversed in other parts of Africa (FAO, 2002). Countries that stand out are Benin, Ghana and Nigeria, but they were the only Sub-Saharan African countries that had consistent declines in both the numbers and the prevalence of undernourished people over the past 20 years.

About 33 percent of people in Sub-Saharan Africa are undernourished, compared to about 6 percent in North Africa and 15 percent in Asia (FAO, 2002). More than 60 percent of the undernourished are in Eastern Africa, with more than half of the populations in Congo Democratic Republic and Mozambique affected, while Angola, Cameroon, Ethiopia, Kenya, Tanzania, and Zambia show prevalence rates between 40 and 50 percent. Nigeria's prevalence rate is low, but its large population means that the country accounts for 22 percent of the food insecure in West and Central Africa.

Achieving food security in Africa is complex. Clearly increased food availability is a necessary component but not a sufficient one. Over the past 20 years, per capita crop and livestock production in Sub-Saharan Africa declined by about 0.2 percent per year (FAO, 2000: 45). In the last 10 years there has been a reversal to an annual per capita increase of 0.3 percent. Hence, while recent production trends per capita have been encouraging, projected aggregate demand growth of 2.8 percent per year to 2015 is likely to exceed projected production growth of 2.6 percent per year over the same period. This will represent a challenge for Africa and implies major food imports in the absence of significant productivity growth.



Food security issues

The 1996 World Food Summit in Rome defined food security as a state when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life. People's food and nutrition security needs vary over their life cycles, as do the implications for their physical and mental health and well-being (Figure 2.1). Food security means far more than having sufficient food on a national basis to meet human needs – whether from domestic production (food self-sufficiency) and/or commercial/aid imports (food self-reliance). Food security today is less a problem of general food availability than of access. People must have access to food. Table 2.1 lists some components of access. Physiological utilization implies that in addition to food access, there are other factors to consider like safe drinking water, primary health care and environmental hygiene to minimize gastro-intestinal infections that can negate the benefits of a nutritious diet. Food security is distinguished from the three forms of hunger – transient, endemic and hidden – which are discussed later.

With increasing urbanization in Africa there is a food and nutritional transition underway leading to problems of overnutrition such as increased obesity, diabetes, hypertension and cardiovascular risks. This is fuelled by supermarkets, new food processing technologies, increased private foreign investment, television and media penetration, and the increasing opportunity costs of time. While this is likely to be a growing problem towards 2015, this report does not address it explicitly. It adopts a narrower definition of food security consistent with its brief to explore the scope for science and technology (s&t) to enhance agricultural productivity, which is much less likely to influence the nutritional transition.

Undernourishment

The FAO (2000: 19-22) uses food balance sheets at national level to assess the extent of undernourishment, as measured by the proportion of the population falling below an Adjusted Average Requirement of 2,600-2,950 kilocalories per person per day, depending on the country and its population structures (age, sex, body weight). Its analysis shows that the incidence of undernourishment in Sub-Saharan Africa has stayed around one-third of the population from the 1970s to the 1990s. In 1995-97 this represented 180 million people. The FAO predicts a significant decline, to 15 percent towards 2030, but this will still number 165 million (40 percent

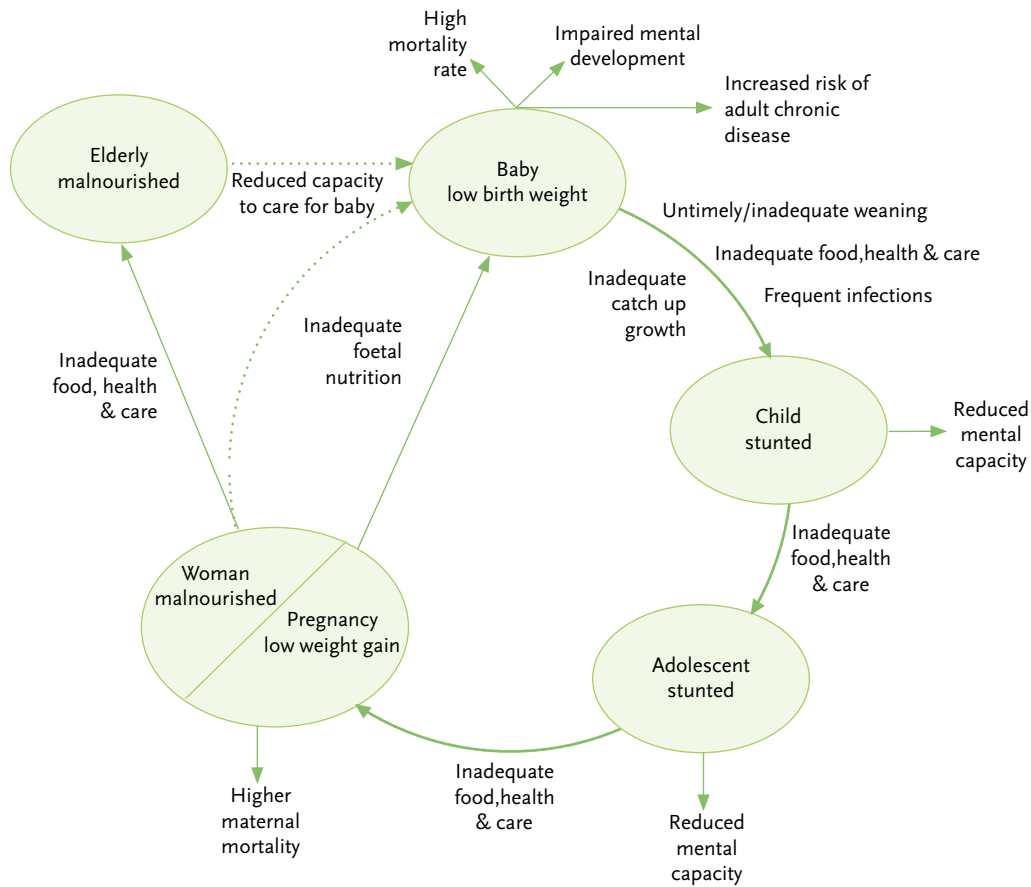


Figure 2.1 The nutritional challenge over the life cycle.
 Source: World Health Organization (1997).

of all undernourished people in the developing world). Less than 10 percent of the population of the Near East/North Africa is undernourished, and this prevalence rate has stayed the same for the past two decades. It currently represents 33 million people and is projected to grow to 38 million by 2015.

Projections to 2020 from the International Food Policy Research Institute (IFPRI) indicate that, as a consequence of poor growth in incomes, poverty is expected to remain pervasive in Sub-Saharan Africa (Pinstrup-Andersen et al., 1999). Food availability should increase marginally but



Table 2.1 Factors involved in attaining food security

Component	Determinant
Physical availability at national level	Is there potentially enough food at the national level to feed all people?
Physical availability at local level	Is food in local markets or in local fields?
Economic access	Does the household generate sufficient income to either purchase food and/or have sufficient diversified home production to meet their requirements?
Social access	Do all household members have equal access to food?
Food quality and safety	Is food of sufficient diversity and safety to promote good health?
Physiological utilization	Are the care and health/sanitation/drinking water environments sufficiently good so that ingested nutritious food can be absorbed and contribute to good growth and development?
Risk of loss of access	How sensitive are any forms of access to shocks and cycles (e.g., seasonality, droughts, and conflict)?
Access as a human right	What is the capacity of the food system to deliver and what is the capacity of individuals to realize their rights to food?

Source: Adapted from Haddad (2001).

remain at the unacceptably low average of 2,276 calories per day (compared to 2,633 for South Asia; 3,008 for Latin America and the Caribbean and 2,902 for the world). The situation in many countries in Sub-Saharan Africa will continue to cause concern, with per capita food consumption reaching only marginally acceptable levels. The FAO predicts that of the 17 countries below the recommended 2,200 kilocalories per person per day in 2015, 12 will be in Sub-Saharan Africa (FAO, 2000).

Child malnutrition

Food security, as indicated in Table 2.1, is a complex set of factors, and undernourishment alone is not considered an adequate indicator. Some consider that child malnutrition, as measured by the numbers or prevalence of low weight-for-age preschool children is the best available indicator. Low food and nutrient intake, poor care for mothers and children and a poor health environment can lead to low weight-for-age (Smith and Haddad, 2000). As with undernourishment for the whole population of Africa, child undernutrition has been an increasing trend over the past three decades, with the prevalence of underweight preschool children rising from around 27 percent in the 1970s to more than one-third (33 million)



currently. It is the only developing region where the numbers of malnourished children have been rising in recent years and if past trends continue, these numbers will continue to increase by about 10 percent to 36 million by 2025 – the only region where this will occur.

The Hunger Task Force of the United Nations Millennium Development Goals program has identified 342 regions of the developing world with more than 20 percent of underweight preschool children. Of these, 72 percent (245) are in Sub-Saharan Africa. Three-quarters of these underweight children are in smallholder rural households while one-quarter is in urban areas. Benin and Ghana have both reduced the prevalence rates of underweight children in recent years, but in Nigeria these have increased, contrary to the trends in undernutrition for its population as a whole. Of the 25 countries of Sub-Saharan Africa analyzed by the Hunger Task Force, only 10 showed reductions in the prevalence of underweight children, with the rest showing increasing trends. The Hunger Task Force did not find any region in North Africa with more than 20 percent of underweight preschool children. The FAO (2002) estimates that rates are much lower in North Africa (4-12 percent) than in Sub-Saharan Africa (13-47 percent). Food insecurity and child malnutrition are much worse in rural than urban areas of Africa. World Health Organization (WHO, 1997) information from 32 African countries shows that in all but one of these countries, the percentage of the preschool children suffering low height-for-age (stunted) is higher in rural than urban areas. In half of the countries the number of stunted children was more than 50 percent higher in rural than urban areas. Estimates of underweight were very similar, with 30 of the 32 countries having a larger percentage of children in rural areas with low weight-for-age.

More than one-half of the 33 million underweight children in Africa are in five of Africa's 17 farming systems: the cereal/root crop based, maize mixed, highland temperate mixed, agro-pastoral sorghum/millet based and the root-crop based (Table 2.2). It is noteworthy that when the densities of underweight children are mapped, those areas where the densities are highest correspond well with areas that also have the highest population densities (see Chapter 3, Figures 3.9A and 3.9C). This seems intuitively obvious on reflection, and it has implications for s&t strategies that will be discussed in Chapters 3 and 4. The Hunger Task Force of the UN Millennium Development Goals program has decided to focus its attention on the 21 'hunger hot spots' in Africa where the child underweight densities are highest.



Transient hunger

The FAO (2002) estimates that 5-10 percent of the global hunger in any given year can be traced to specific shocks like droughts, floods, armed conflict, or political, social and economic disruptions. This is termed transient or acute hunger, and there is little direct contribution from agricultural productivity growth to alleviating this type of hunger – except that its effects will be more severe where productivity growth trends have been lower. The numbers of people affected by conflict in the world have fallen in the 1990s from around 40 million to 20 million. However the numbers affected by natural disasters have risen from 40 million to more than 70 million in the same period (Hoddinott, 2003).

Table 2.2 The extent of child malnutrition in Sub-Saharan Africa farming systems

Farming system	Total no. of children < 5 years (million)	Underweight children < 5 years	
		Number (million)	Proportion (%)
Cereal/root crop mixed	15.51	4.92	31.7
Maize mixed	16.33	4.07	25.0
Highland temperate mixed	7.65	3.28	42.9
Agro-pastoral sorghum/millet based	9.38	3.20	34.1
Root crop based	12.29	3.21	26.2
Pastoral	8.25	2.72	32.9
Highland perennial	8.16	2.55	31.2
Forest based	7.86	2.18	27.7
Tree crop based	8.14	1.73	21.3
Coastal artisanal fishing	7.36	1.56	21.2
Irrigated	9.63	1.10	11.4
Rice/tree crop based	2.00	0.83	41.6
Sparse arid	2.00	0.52	26.2
Large commercial and smallholder	4.00	0.33	8.4
Dryland mixed	2.73	0.17	6.1
Rainfed mixed	3.15	0.16	5.1
Highland mixed	0.41	0.04	9.6
Total	124.85	32.57	26.1

Note: These data were provided by the Hunger Task Force of the UN Millennium Development Goals, from the analysis by the Center for Earth Science Information Network (CIESIN) at Columbia University, New York. The farming systems are defined by Dixon et al. (2001) and more fully described in Chapter 3, Box 3.2.



Africa has had a disproportionate share of such shocks. However many food insecure countries have been relatively free of them, so the absence of such shocks does not guarantee food security. Indeed food insecurity and conflict derive from a common set of risk factors. These risk factors include poor economic conditions, repressive political systems, weak institutions, natural resource degradation, scarce resources and unequal access to them, productivity declines, rapid poverty growth, social and cultural polarization and large-scale migration. Hence, addressing these risk factors can both prevent conflict and reduce hunger.

Food aid is one of the most effective devices for alleviating transient hunger in such emergencies. It is noteworthy that per capita food aid in conflict countries has risen over the period whereas in natural disaster countries it has fallen (Hoddinott, 2003). Conflict and natural disasters are termed covariant shocks, in that large numbers of households are simultaneously affected. In such situations, food aid is the most effective insurance mechanism to reduce vulnerability to transient hunger and starvation, as households have few options. Other shocks, such as adult illness, are more idiosyncratic to the household, and they do better at offsetting such shocks.

Endemic and hidden hunger

Endemic or chronic hunger is of a more permanent nature, caused by poverty and lack of access to balanced diets including both energy-rich and protein-rich foods, leading to protein-energy malnutrition. Productivity growth can play a major role in alleviating this insidious form of hunger. Billions of people in developing countries also suffer from hidden hunger, caused by a deficiency in micronutrients such as folate, iodine, iron, selenium, and vitamins A and C. After Asia, Africa has the highest prevalence rate of hidden hunger, with pregnant and lactating women and preschool children most at risk (FAO, 2002; CGIAR, 2002; Graham et al., 2001).

Micronutrient malnutrition can damage cognitive development, lower disease resistance in children and reduce the likelihood that mothers survive childbirth. Lack of dietary diversity is a key causal factor. Increasing the amount and variety of micronutrient-dense fruits, vegetables, livestock and fish products in diets can alleviate this form of hunger. Income growth leads to a more diversified diet, and again agricultural productivity growth is the primary ingredient for this in Africa. It can also contribute to lowering the prices of micronutrient-dense foods, thus allowing the mal-



nourished better access to them. Food fortification is another strategy, as in the case of iodized salt. More recently biofortification has become another possibility, by manipulation of the genes controlling micronutrient content in staple foods such as rice.

Changing demographics, health and climate

The nature of farming is changing in many African countries because of demographic changes: the farm population is aging, rural male workers are migrating to urban areas, and many rural areas are becoming urbanized. These changes imply an increasingly diverse clientele for agricultural research and the need to give much more attention to women farmers and older farmers. Moreover, although most rural poor Africans still depend heavily on agriculture for their livelihoods, many also have diversified into non-farm income sources, including own small-scale, rural non-farm enterprises; non-farm employment; and seasonal migration. As a result, many small farms may give lower priority to farming than non-farm activities and may not take up promising new technology options that compete for labour. On the other hand, more diversified households may have more capital of their own to invest in new agricultural technology options and resource improvements and be better able to withstand shocks and risks.

With rapid population growth, the per capita availability of natural resources is declining in rural Africa; and many farms are becoming too small to fully support farm families. At the same time, resources are being degraded, reducing their productivity and the quality of environmental services they provide. In this context, agricultural research must focus on activities that enhance resource productivity and on natural resource management practices that can reverse degradation.

Global and regional climate change could have several important consequences for African agriculture. Growing conditions may deteriorate in some tropical areas and there are likely to be more frequent and severe droughts in many arid and semi-arid areas. Such events will add to the burdens of existing farming systems, reducing their average productivity and resilience, and thus increasing the vulnerability of poor people who depend on these farming systems. Given the long lead times inherent in much agricultural research, these changes need to be anticipated in setting research priorities for the future. Such priorities should consider both changed crop characteristics and changes in cropping systems.



HIV/AIDS is rampant and spreading in Africa. It is killing large numbers of working adults, reducing the labour available for farming, turning millions of children into orphans, and disrupting the transmission of agricultural knowledge from one generation to the next. Where new technology options are introduced into afflicted areas they will have to contend with increasing labour costs and labour shortages, and farm families will need help with labour-saving technology options (including appropriate mechanization) and nutritionally enhanced foods. HIV/AIDS is also affecting the scientific population of Africa, a resource that is already scarce.

Possible strategic options

Role of productivity growth in food security

In the last four decades in Africa, less than 40 percent of the gains in cereal production came from increased yields. The rest was from expansion of the land devoted to arable agriculture (Runge et al., 2003: 71). In future, Africa must depend more on yield gains than land expansion to achieve food security. In the past two decades, cereal yield growth in Sub-Saharan Africa was virtually stagnant, whereas it grew by about 2.3 percent per year in West Asia/North Africa (Rosegrant et al., 2001: 63).

Much of the expansion of arable farming in Africa was at the expense of forests, soil fertility and water. Producing more food per unit of land suited for agriculture, in a manner compatible with sustainable management of natural resources, is an essential component of a successful effort to eliminate food insecurity and malnutrition. More production per person engaged in agriculture is also essential, particularly at this time when devastating problems such as HIV/AIDS, malaria, and tuberculosis have reduced the capacity of the African labour force. Finally, risk factors such as drought and pests and market risks and uncertainties contribute significantly to food insecurity and malnutrition.

Improving agricultural productivity is a means of increasing both the physical availability of food and the incomes of food-insecure people. In this respect, it offers a key and direct ingredient in the first three of the eight factors important for achieving food security listed in Table 2.1. It also can contribute indirectly to the others by way of providing the added public and private resources to invest in improved infrastructure, services and safety nets. However, increased productivity and food availability leading to reduced real food prices are not sufficient to eradicate food insecurity.



Agricultural productivity growth in Africa is vital in attaining food security because agriculture represents 70 percent of full-time employment, 33 percent of gross domestic product (GDP) and 40 percent of its exports earnings (IFPRI, 2002). Agricultural productivity growth is hence the engine of economic growth. Also more than three-quarters of the poor and hungry in Sub-Saharan Africa reside in rural areas and depend on agriculture for their livelihoods, either directly or indirectly. Indeed the dependence on agriculture is greater in those countries where hunger is most prevalent (FAO, 2002). Smallholders dominate the sector and have shown a capability of adopting new technology options where the right incentives and market opportunities exist.

Recent IFPRI research shows that each 10 percent increase in smallholder agricultural productivity in Africa can move almost 7 million people above the dollar-a-day poverty line (IFPRI, 2000). Currently there are some 110 million Sub-Saharan Africans below this poverty line. Due to the growth multipliers between agriculture and the rural non-farm sector the urban poor benefit along with the rural poor from broad-based agricultural productivity growth. As a rule-of-thumb, IFPRI has estimated that for every dollar of additional income created in the agricultural sector, society as a whole will grow by about 2.5 dollars. The IFPRI research also suggests that income-increasing productivity enhancements among smallholders tend to be particularly powerful in efforts to reduce poverty, both inside and outside agriculture.

Agricultural research and development (R&D) investments are one of the most crucial determinants of agricultural productivity growth, besides basic education. Investments in research to develop risk-reducing and productivity-enhancing technology are of critical importance.

Improve care for mothers and children

It seems in Sub-Saharan Africa that, just ahead of health improvements, improvements in food availability and female education (impacting on maternal and child care) are the most significant factors in reducing child malnutrition. According to projections by Runge and colleagues (2003: 48-52), the good news is that with significant increases in agricultural productivity and economic growth, reductions in population growth rates, and increased investments in education and health, the number of underweight children in Sub-Saharan Africa could be reduced by more than one-third to 22 million by 2025. To achieve this, crop yields would have to increase by 3 percent annually, and total GDP by 8-10 percent each year.



These far exceed recent growth rates. For example from 1982-1997 cereal yields grew by only 0.1 percent per year and GDP by 2.8 percent per year from 1991-1998 (FAO, 2000: 28). In West Asia/North Africa this projection scenario would result in a two-thirds reduction of underweight children, to 2 million.

Invest in development

According to projections by Runge and colleagues (2003), trend investments in rural roads, irrigation, clean water, education and agricultural research also would have to increase by about 80 percent to achieve these outcomes. Such rates of increase may sound too optimistic, but they are not unprecedented. They occurred in Asia during the Green Revolution. The essential point here is that the decline in the real price of food – facilitated by crop yield growth from increased investments in agricultural research, infrastructure and environmental protection – drives increased access to food, with consequent reductions in undernutrition and especially child malnutrition.

Focus on rural areas

More than 85 percent of the poor in Sub-Saharan Africa reside in rural areas (Randolph et al., 2001). Also the prevalence rates of child malnutrition in rural areas are generally equal to or up to double those in urban areas (Wolgin, 2001; and UNICEF, 2003). In North Africa the situation seems different. There only 48 percent of the poor are in rural areas. However, the prevalence rates of child malnutrition in rural areas are more than double those in urban areas. Action to eliminate food insecurity and malnutrition in Africa therefore must focus on rural areas for a long time to come, even though the rates of urbanization in Africa are rapidly increasing. The large majority of food-insecure rural Africans depend directly or indirectly on agriculture.

Secure land tenure

In a cross-country analysis, the FAO (2002) estimates that more equal access to land and increased tenure security result in more rapid growth in GDP and reduced prevalence of undernourishment. Tenure security can be achieved by respecting decentralized customary tenure and does not require centralized top-down land tenure and titling reforms. Land tenure security also provides the safety required for productivity-enhancing and longer-run technology investments to be made.



Gain from science and technology

Areas where science and technology can directly contribute to improved food security and alleviate hunger in all its forms include:

(a) Physical availability

- Improved drought, pest and disease tolerance, yield potential and the nutrient content of food crops from plant breeding/molecular biology;
- Increased nutrient and water use efficiencies from plant breeding/molecular biology;
- Labour-saving technologies, with greater mechanization especially in HIV/AIDS affected communities;
- Technologies like global positioning systems to help track food aid shipments;
- Institutional and technological innovations such as rainfall insurance to link local insurance to global risk-pooling institutions.

(b) Economic access

- Increasing productivity in food production, leading to increased incomes and improvements in purchasing power;
- Technology options like cell phones and the Internet that help get crops and livestock to market at lower cost and with improved price transmission;
- Increased attention to value addition for food staples, horticulture, and animal products through postharvest research and development on processing, packaging and marketing, which can enhance non-farm income opportunities.

(c) Social access

- Technology options that are especially accessible to women – given their indispensable role in ensuring household food security – and allow child care at the same time, such as advice and assistance with home vegetable gardens.

(d) Physiological utilization

- Technologies for successful food fortification and water purification;
- Nutrient supplementation and biofortification;
- Access to safe water and health/hygiene services.

Conclusions

The rate of increase in undernourishment in Africa vastly exceeds that of other developing regions. Achieving food security is imperative, but how to do so is an elusive, complex problem. Part of the problem is the very low current and past levels of investment in productivity-increasing measures



in African agriculture, which have meant high unit costs of production and progressive environmental degradation. The results are low incomes for farmers and other rural residents, reduced competitiveness, and increasing food insecurity and child malnutrition.

The near stagnant economies in parts of Africa are to a large extent a reflection of stagnant agriculture. Lower unit costs in production, resulting from productivity increases, would lead to lower consumer prices for food and higher farm incomes, which, in turn, would promote economic growth through lower wage costs, higher investments, and increasing consumer demand outside agriculture. Smallholder-led economic growth could lead to dramatic improvements in food security and nutrition.

Science and technology can directly contribute to food security through improved crops and cropping practices, labour-saving technologies, better communications, and improved quality of food processing, packaging and marketing. Women and children must be major beneficiaries of any advances.



References

- CGIAR (Consultative Group on International Agricultural Research). 2002. Biofortified crops for human nutrition: A CGIAR challenge program proposal draft, June 25. Washington, DC
- Dixon, J., A. Gulliver, and D. Gibbon. 2001. Farming systems and poverty: Improving farmers livelihoods in a changing world. FAO, Rome, and World Bank, Washington, DC
- FAO (Food and Agriculture Organization). 2000. Agriculture: Towards 2015/30. Technical interim report, April. Economic and social department. Rome, Italy.
- FAO. 2002. Food insecurity: When people must live with hunger and fear starvation. The state of food insecurity in the world 2002. FAO. Rome, Italy.
- Graham, R.D., R.M. Welsch, and H.E. Bouis. 2001. Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: Principles, perspectives and knowledge gaps. *Advances in Agronomy*, 70: 78-142.
- Haddad, L. 2001. Deepening the analysis of the factors behind progress towards wfs targets. ODI discussion paper. London, U.K.
- Hoddinott, J. 2003. Food aid in the 21st century: Food aid as insurance. Paper presented at international workshop, Defining the role of food aid in contributing to sustainable food security, Berlin, September. International Food Policy Research Institute. Washington, DC.
- IFPRI (International Food Policy Research Institute). 2002. Ending hunger in Africa: Only the small farmer can do it. International Food Policy Research Institute. Washington, DC.
- Pinstrup-Andersen, P., R. Pandya-Lorch, and M.W. Rosegrant, 1999. World food prospects: Critical issues for the early twenty-first century. 2020 Vision Food Policy Report. International Food Policy Research Institute. Washington, DC.
- Randolph, T. F., P. M. Kristjanson, S. W. Omamo, A. N. Odera, P. K. Thornton, R. S. Reid, T. Robinson, and J. G. Ryan. 2001. A framework for priority setting in international agricultural livestock research. *Research Evaluation*, 10(3): 142-160.
- Rosegrant, M. W., M. S. Paisner, S. Meijer, and J. Witcover. 2001. Global food projections to 2020: Emerging trends and alternative futures. International Food Policy Research Institute. Washington DC.
- Runge, C. Ford, B. Senauer, P.G. Pardey, and M.W. Rosegrant. 2003. Ending hunger in our lifetime: Food security and globalization. International Food Policy Research Institute. Baltimore and London: Johns Hopkins University Press.
- Smith, L.C., and L. Haddad. 2000. Overcoming child malnutrition in developing countries: Past achievements and future choices. Food, agriculture, and the environment discussion paper 30. International Food Policy Research Institute. Washington, DC.
- UNICEF (United Nations Children's Fund). 2003. UNICEF statistics. <www.unicef.org/pon99/dicedatr.htm>
- Wolgin, J. M. 2001. A strategy for cutting hunger in Africa. Commissioned paper by Technical Committee of Partnership to Cut Hunger in Africa <www.aec.msu.edu/agecon/fs2/africanhunger/wolgin_eng5.htm>
- WHO (World Health Organization). 1997. Third report on the world nutrition situation. Administrative Committee on Nutrition/Subcommittee on Nutrition (ACC/SCN). Geneva.



3. African agricultural production systems and productivity in perspective

African farmers pursue a wide range of crop and livestock enterprises that vary both across and within the major agro-ecological zones. Food production and food security in Africa depend on many different systems, unlike other regions of the world where the contribution to food production and food security is based on a limited number of systems. For the foreseeable future in Africa a multitude of farming systems need to become more productive and to generate the desired productivity increases outlined in chapter 2. This chapter describes and characterizes the major farming systems, analyses recent trends in productivity and identifies priority systems which offer the best prospects for measurable gains in productivity and food security.

Farming/production systems in Africa

Diversity is the norm in African farming systems. Even at the level of the individual farm unit, farmers typically cultivate 10 or more crops in diverse mixtures that vary across soil type, topographical position and distance from the household compound. Dixon and colleagues (2001) provide the most comprehensive description of farming systems globally (Table 3.1 and Figure 3.1). They identify and broadly delimit farming systems based on the (a) natural resource base; (b) dominant livelihoods (main staple and cash income source – a balance between crops, livestock, fishing, forestry and off-farm activities); (c) degree of crop-livestock integration and (d) scale of operation. The main characteristics of the major farming systems in Africa are shown in Table 3.1. Analysis of various systems has shown that mixed cropping systems reduce risk, reduce crop losses from pests and diseases and make more efficient use of farm labour. Science and technology (s&t) investments are embodied in these systems' commodities and resource management practices in often complex and interdependent ways.

Farming systems in Sub-Saharan Africa comprise many root crops, especially cassava. Cereals are less important. The main crops are coarse



grains like millet and sorghum, followed by maize. The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed by the International Food Policy Research Institute (IFPRI) to project the future demand for these commodities, estimated that the per capita demand for cereal crops will increase in Sub-Saharan Africa by some 4.9 percent per year between 1997 and 2020, with the main increase in wheat and rice (Rosegrant et al., 2001). Part of the increase will be due to greater demand for animal feed. The demand for root and tuber crops will increase by about 65 percent, more or less evenly spread over all species.

The farming systems described provide a snapshot of dynamic systems that are constantly evolving. Both endogenous factors (household goals, labour, technologies in use and the resource base) and exogenous factors (market development, shifts in demand, agricultural services and policies, the dissemination of new technologies and the availability of market and policy information) drive the evolution of individual farms and, collectively, the overall farming system.

Farming systems may evolve along several pathways. Population growth combined with new technology options and/or market opportunities can induce farmers to diversify and intensify systems. Depending on the natural resource base and management systems, intensification can either sustain and improve productivity over time, or degrade the natural resource base and therefore lower production potential over time. On the other hand, population growth in the absence of technological or market opportunities can lead to deepening poverty, degradation of the resource base and long-term agricultural involution.

Over decades, farming systems may differentiate into subtypes that continue to evolve along different pathways. For example, in systems under population and market pressure, some farms may successfully intensify and even specialize to produce for the market, whereas others may regress to low-input/low-output systems. Moreover, in any one location within a farming system, different farms are likely to be at different stages of evolution because of differentiated resource bases, household goals, capacity to bear risk or degree of market access. Individual farm systems may also be shifted out of the overall trajectory of system evolution because of shocks – internal (such as family sickness), external (natural disasters) or policy (such as structural adjustment).



Table 3.1 Farming systems of Sub-Saharan Africa, North Africa and the Middle East

Farming system	Land area (% of region)	Agric. popul. (% of region)	Principal livelihoods
Region: Sub Sahara Africa			
Maize mixed	10	15	Maize, tobacco, cotton, cattle, goats, poultry, off-farm work
Cereal/root crop mixed	13	15	Maize, sorghum, millet, cassava, yams, legumes, cattle
Root crop	11	11	Yams, cassava, legumes, off-farm income
Agro-pastoral millet/sorghum	8	9	Sorghum, pearl millet, pulses, sesame, cattle, sheep, goats, poultry, off-farm work
Highland perennial	1	8	Banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry, off-farm work
Forest based	11	7	Cassava, maize, beans, cocoyams
Highland temperate mixed	2	7	Wheat barley, teff, peas, lentils, broadbeans, rape, potatoes, sheep, goats, cattle, poultry, off-farm work
Pastoral	14	7	Cattle, camels, sheep, goats, remittances
Tree crop	3	6	Cocoa, coffee, oil palm, rubber, yams, maize, off-farm work
Commercial – largeholder and smallholder	5	4	Maize, pulses, sunflower, cattle, sheep, goats, remittances
Coastal artisanal fishing	2	3	Marine fish, coconuts, cashew, banana, yams, fruit, goats, poultry, off-farm work
Irrigated	1	2	Rice, cotton, vegetables, rainfed crops, cattle, poultry
Rice/tree crop	1	2	Rice, banana, coffee, maize, cassava, legumes, livestock, off-farm work
Sparse agriculture (arid)	18	1	Irrigated maize, vegetables, date palms, cattle, off-farm work
Urban based	<1	3	Fruit, vegetables, dairy, cattle, goats, poultry, off-farm work
Region: North Africa/Middle East			
Highland mixed	7	30	Cereals, legumes, sheep, off-farm work
Rainfed mixed	2	18	Tree crops, cereals, legumes, off-farm work
Irrigated	2	17	Fruits, vegetables, cash crops
Dryland mixed	4	14	Cereals, sheep, off-farm work
Pastoral	23	9	Sheep, goats, barley, off-farm work
Urban based	<1	6	Horticulture, poultry, off-farm work
Sparse (arid)	62	5	Camels, sheep, off-farm work
Coastal artisanal fishing	1	1	Fishing, off-farm work

Source: Dixon et. al. (2001)



Box 3.1 Importance of livestock in African farming systems

Livestock contribute to livelihood strategies of the poor and food insecure in many ways. They are an important source of cash income, and one of their few liquid and mobile assets that offer risk management options to reduce vulnerability, social networking instruments and social security capital.

They provide the following benefits:

- Manure and draft power to enhance soil fertility and facilitate facility to sustainable intensification of farming systems;
- Transport to markets and power for post-harvest operations;
- Usage of common property grazing lands, which are especially vital to the welfare of the landless;
- Source of income diversification; and
- High-quality protein and energy to diets of the food and nutrition insecure, as well as essential micronutrients such as calcium, iron, zinc, retinal, thiamin, zinc, and vitamins A, B6 and B12, often lacking in cereal-based diets.

Livestock are an integral part of the agricultural systems of Africa and especially important to the poor (Box 3.1), who derive a larger proportion of their meagre incomes from livestock than do the wealthier (Delgado et al., 1999).

Perry and colleagues (2002) discuss the importance of livestock in African farming systems at length. They define animal production systems according to their major characteristics and agro-ecological zoning (Table 3.2). Further, they differentiate between these systems in West Africa and in Eastern/Central/Southern Africa.

In the mixed crop-livestock systems of the arid/semi-arid (MRA), humid/subhumid (MRH) and tropical highlands (MRT) of Eastern, Central and Southern Africa, cattle are judged of greatest importance to the poor, followed by sheep and goats, poultry, horses, donkeys and mules, with pigs last. By contrast in the same systems in West Africa, sheep and goats rank highest, followed by poultry and cattle, then horses, donkeys and mules, with pigs again last. In the pastoral rangeland-based systems in Africa, sheep and goats are generally regarded as of highest relevance to the poor, followed by cattle, camels and horses, donkeys and mules.

In Sub-Saharan Africa the total output of animal products is worth most in the pastoral rangeland-based systems in the arid/semi-arid region (IGA), followed by the mixed rainfed crop-livestock systems in the humid/subhumid tropics (MRH) and then the mixed rainfed crop-livestock systems in the arid/semi-arid tropics (MRA) (ILRI 2000). However there are more than twice as many poor people dependent on the mixed rainfed crop-livestock systems in the humid/subhumid tropics (MRH) than depend on the other two systems. In West Asia/North Africa by far the most economically important livestock production system is the mixed rainfed crop-livestock system in the arid/semi-arid tropics (MRA). However it supports less than one-third of the numbers of poor people than are supported by the humid/subhumid system in Sub-Saharan Africa. More than 60 percent of the poor in West Asia/North Africa are in West Asia (Thornton et al., 2002).

The three mixed rainfed crop-livestock systems (MRA, MRH and MRT) represent more than 70 percent of the estimated 280 million poor people in Sub-Saharan Africa (Thornton et al., 2002). The pastoral rangeland-based systems support around 10 percent. In North Africa the mixed irrigated arid/semi-arid crop-livestock system (MIA) comprises 44 percent of the total poor in the region, while the three mixed rainfed crop-livestock systems represent only 25 percent.

Demand for meat and milk is projected to more than double over the



Table 3.2 Major animal production systems in African agro-ecological zones

Abbreviation	Animal production system	Agro-ecological zone
LGA	Pastoral, livestock only, rangeland-based	arid/semi-arid
LGH	Pastoral, livestock only, rangeland-based	humid/subhumid
LGT	Pastoral, livestock only, rangeland-based	temperate/tropical highland
MRA	Agro-pastoral, mixed rainfed	arid/semi-arid
MRH	Agro-pastoral, mixed rainfed	humid/subhumid
MRT	Agro-pastoral, mixed rainfed	temperate/tropical highland
MIA	Agro-pastoral, mixed irrigated	arid/semi-arid
MIH	Agro-pastoral, mixed irrigated	humid/subhumid
LL	Peri-urban, landless	

Source: Perry et al. (2002). Includes both Sub-Saharan and North Africa.

next two decades in developing countries. The major factors driving this rising demand are population growth, increased urbanization and higher incomes. Sub-Saharan Africa is projected to have the greatest annual growth in consumption of meat (3.5 percent) of any other region and the second highest growth of milk consumption (3.8 percent). These far exceed growth projections in demand for foodgrains. Because livestock are an important livelihood asset for the poor in Africa, this ‘Livestock Revolution’ (Delgado et al., 1999) has the potential to provide a platform for the poor in Africa to reap a disproportionate share of the benefits of this demand growth.

If livestock production is to keep pace with demand the imperative is to enhance productivity per animal and reduce wastage. In Sub-Saharan Africa, recent productivity growth per animal has been far less than the projected growth rates of demand for all species. Productivity growth has ranged from -0.5 to 0.6 percent per year while demand growth is projected to be between 2.6 and 4.2 percent per year (ILRI, 2000). In West Asia/ North Africa the demand – productivity growth gap is not nearly as large as in Sub-Saharan Africa.



Box 3.2 Farming system characteristics

The range of farming systems practiced across the African continent is described below and arrayed in Figure 3.1, according to Dixon and colleagues (2001).

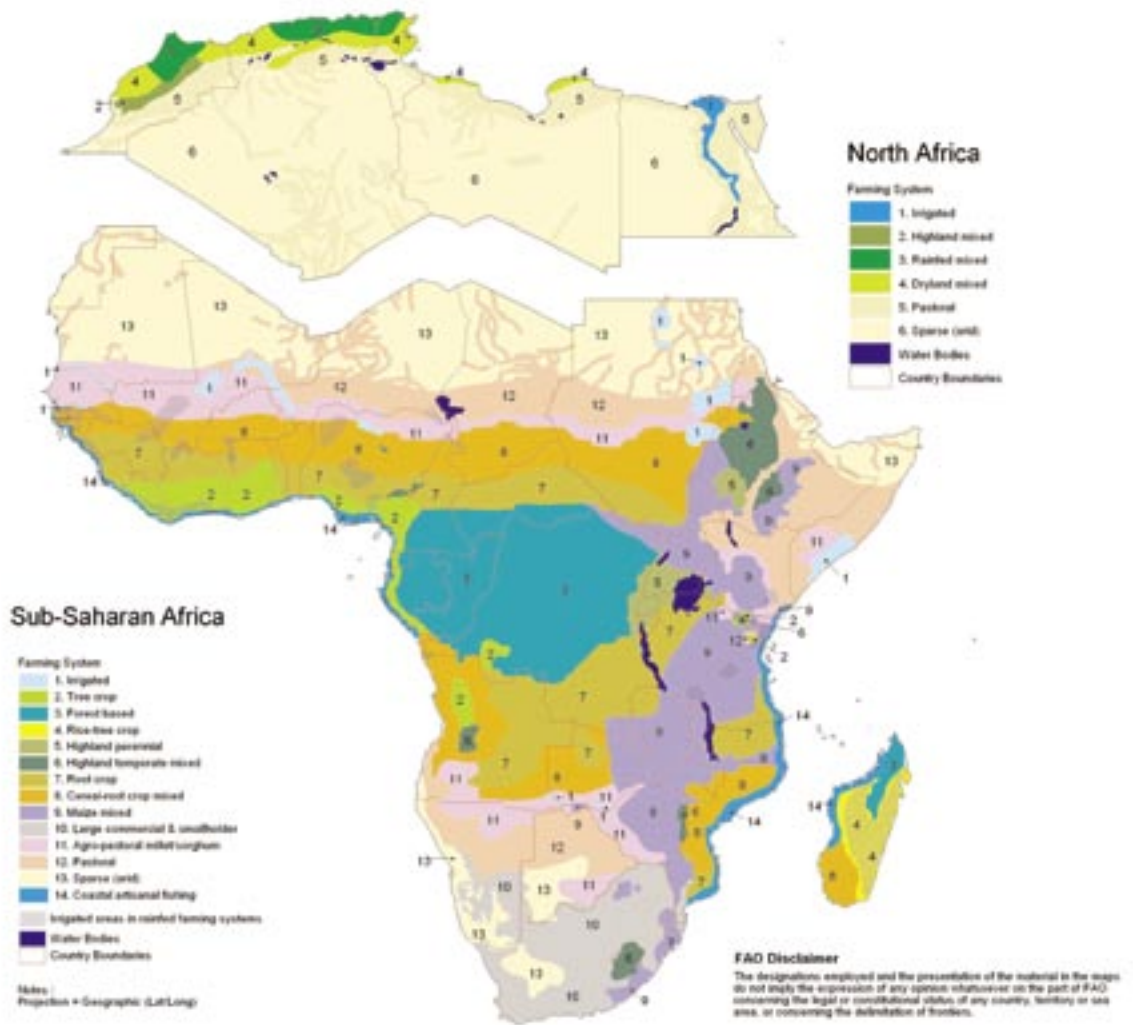


Figure 3.1 African farming systems according to Dixon et al. (2001)



Maize mixed system (10 percent land area, 15 percent agriculture population in Sub-Saharan Africa)

This farming system is the most important food production system in East and Southern Africa, extending across plateau and highland areas. In West Africa similar systems are found in the highlands of western Cameroon and Nigeria. Climate varies from dry subhumid to moist subhumid. The farming system also contains some scattered mostly small-scale irrigation schemes. The main staple is maize and the main cash sources are migrant remittances, cattle, small ruminants, tobacco, coffee and cotton, plus sale of food crops such as maize, pulses and sunflower. Cattle are kept for ploughing, breeding, milk, farm manure, bride wealth, savings and emergency sale. In spite of scattered settlement patterns, community institutions and market linkages in the maize belt are better developed than in other farming systems.

Smallholders are vulnerable to drought and market volatility, and socio-economic differentiation is considerable due mainly to migration. But the system is currently in crisis: input use has fallen sharply due to the shortage of inputs such as seed and fertilizer and the high price of fertilizer. Consequently yields have fallen, and soil fertility is declining, while smallholders are reverting to extensive production practices, which are not very sustainable given their small farm sizes. Off-farm income is important for most households.

Cereal/root crop mixed system (13 percent land area, 15 percent agriculture population in Sub-Saharan Africa)

This farming system is mainly in the Guinea savannah. It shares some characteristics with the maize mixed system (such as 120–180 growing days with, in some areas, monomodal rainfall) but is located at lower altitude. Defining characteristics are relatively low population density, abundant arable land, poor communication infrastructure and higher temperatures. Presence of tsetse fly limits livestock numbers with consequent absence of animal traction in much of the area. Cereals such as maize, sorghum and millet are important, but wherever animal traction is absent, root crops such as yams and cassava take over. A wide range of crops is grown, and intercropping is important. The main vulnerability is drought, but the Guinea savannah represents one of the main under-utilized resources in the region. The abundant arable land tends to be under-utilized. Although crop rotation is possible, there are signs of fertility decline. Acidity has increased in some soils suggesting prolonged use of inorganic fertilizers without attention to organic matter levels. Application of mineral fer-

tilizer to cereals has declined as they have become less affordable, and farmers now find difficulty in maintaining soil fertility. Weeds such as striga have become more difficult to control. In the northern part of the area, prolonged use of mechanization for land preparation has led to loss of soil structure and organic matter.

Root crop system (11 percent land area, 11 percent agriculture population in Sub-Saharan Africa)

This farming system is situated in and extends from Sierra Leone to Benin, Cameroon, Côte d'Ivoire, Ghana, Nigeria and Togo. The area is bounded by and merges into the tree crop and forest-based farming systems on the southern, wetter side and into the cereal/root crop mixed farming system on the northern, drier side. Rainfall is either bimodal or nearly continuous, and risk of crop failure is low. As in the tree crop systems, fluctuating demand for industrial crops constitute an important source of vulnerability, as well as emerging soil fertility problems. Agricultural growth potential and poverty reduction potential are moderate; technologies for this system are not yet fully developed. Nonetheless, market prospects for export of oil palm products are attractive, urban demand for root crops is growing, and linkages between agriculture and off-farm activities are relatively well developed.

Agro-pastoral millet/sorghum system (8 percent land area, 8 percent agriculture population in Sub-Saharan Africa)

This farming system occurs generally in the semi-arid zone of West Africa from Senegal to Niger and in substantial areas of East and Southern Africa from Somalia and Ethiopia to South Africa. Population density is modest, but pressure on arable land is very high. Crops and livestock are of similar importance. Rainfed sorghum and pearl millet are the main sources of food and are marketed in small quantities, with occasional sales of sesame and pulses. Land preparation is by oxen or camel, while cultivation with hoes is common along riverbanks. Livestock provide milk and milk products; offspring; transportation (camels, donkeys); land preparation (oxen, camels); sale or exchange; savings; bride wealth and insurance against crop failure. The population tends to live in permanent villages, although part of their herds may continue to migrate seasonally with herd boys and through entrustment arrangements.

The main vulnerability is drought. The farming system has suffered from insufficient and erratic rainfall during the past two decades, leading to low crop yields and the abandonment of groundnuts and late-maturing sorghum in



some areas. There is an acute shortage of drinking water and firewood in certain areas. Soil fertility problems are emerging in the plains due to shortened fallow intervals and long periods of continuous cultivation. Land shortage is also a problem in the densely populated areas where soils are more fertile. Pressure on resources is expected to intensify in coming decades with the growth of human and livestock populations in the system.

Highland perennial system (1 percent land area, 8 percent agriculture population in Sub-Saharan Africa)

This farming system occurs mainly in Burundi, Ethiopia, Rwanda, and Uganda. It supports Africa's highest rural population density (more than one person per hectare of land). Land use is intense and holdings are very small (average cultivated area per household is just under 1 hectare, but more than 50 percent of holdings are smaller than 0.5 hectare). The farming system is based on perennial crops such as banana, plantain, enset (Ethiopian false banana) and coffee, complemented by cassava, sweet potato, beans and cereals. Cattle are kept for milk, manure, bride wealth, savings and social security. The main constraints are diminishing farm size and declining soil fertility, leading to increasing poverty and hunger. People cope by working the land more intensively, but returns to labour are low.

Forest-based system (11 percent land area, 7 percent agriculture population in Sub-Saharan Africa)

This farming system occurs in the humid forest zone. It is found in the Congo Democratic Republic, the Congo Republic, Equatorial Guinea, Southeast Cameroon, and Gabon. Farmers practise shifting cultivation, clearing a new field from the forest every year, cropping it for 2 years (first cereals or groundnuts, then cassava) and then abandoning it to bush fallow for 7-10 years. Cassava is the staple, complemented by maize, sorghum, beans and cocoyam. Cattle populations are low. Population density is also low and physical isolation plus lack of roads and markets are serious problems. Forest products and wild game are the main source of cash, but cash is in short supply because few households have cash crops and market outlets are distant.

Agricultural growth potential is moderate thanks to the existence of large uncultivated areas and high rainfall, but yield increases in the near future are expected to be modest. Development entails environmental risks, including soil fragility and loss of wildlife habitats.

Highland temperate mixed system (2 percent land area, 7 percent agriculture population in Sub-Saharan Africa)

This is the system of the highlands and mountains of Eritrea, Ethiopia, and Lesotho, and also to a small extent in Angola, Cameroon, Kenya and Nigeria. Average population density is high and average farm size is small (1-2 hectare). Cattle are numerous and are kept for ploughing, milk, manure, bride wealth, savings and emergency sale. Small grains such as wheat and barley are the main staples, complemented by peas, lentils, broad beans, rape, teff (in Ethiopia) and Irish potatoes. The main sources of cash are from the sale of sheep and goats, wool, local barley beer, Irish potatoes, pulses and oilseeds. Some households have access to soldiers' salaries (Ethiopia and Eritrea) or remittances (Lesotho), but these mountain areas offer few opportunities for local off-farm employment.

Major problems include soil fertility decline, in part because of a shortage of organic matter, and cereal production suffers through lack of inputs. Household vulnerability stems mainly from the risky climate: early and late frosts at high altitudes can severely reduce yields, and crop failures are not uncommon in cold and wet years. Agricultural growth potential is only moderate, but there is considerable potential to diversify into higher-value temperate crops.

Pastoral farming system (23 percent land area, 9 percent agriculture population in Middle East and North Africa; 14 percent land area, 7 percent agriculture population in Sub-Saharan Africa)

Pastoral systems, mainly involving sheep and goats, are found across large areas of the arid and semi-arid zones of Africa. (Temperate area pastoralists such as the Masai are included in the highland temperate systems.) Such systems have strong linkages to farming systems in more humid areas and to large feedlots located in urban areas. The animals undertake seasonal migration, which relies on the availability of grass, water and crop residues. For example, during the driest period of the year, Sahelian pastoralists move south to the cereal/root crop mixed system areas and they return north during the rainy season. These systems are often partially controlled and financed by urban capital.

The vulnerabilities of pastoral systems include the great climatic variability and consequently high incidence of drought and desertification, leading to loss of biodiversity; loss livestock due to droughts or stock theft; and heavy grazing of the rangelands by livestock, believed to be the main cause of degradation to vegetation and land throughout the pastoral regions.



Tree crop based system (3 percent land area, 6 percent agriculture population in Sub-Saharan Africa) and **rice/tree crop mixed system** (1 percent land area, 2 percent agriculture population in Sub-Saharan Africa)

The tree crop farming system runs from Côte d'Ivoire to Ghana and from Nigeria and Cameroon to Gabon, with smaller pockets in the Democratic Republic of the Congo. The backbone of the system is the production of industrial tree crops – notably cocoa, coffee, oil palm and rubber. Food crops are inter-planted between tree crops and are grown mainly for subsistence. Roots and tubers (cassava, cocoyam and yam) are the main staples; tree crops and off-farm activities are the main sources of cash. Livestock keeping is limited by tsetse fly infestation in many areas, and land preparation is by hand. The main animal species are pigs and poultry. Fish farming is popular in some areas. Off-farm activities are relatively well developed. There are also commercial tree crop estates (particularly for oil palm and rubber) in these areas, providing services to smallholder tree crop farmers through nucleus estate and outgrow schemes. A variant of the tree crop system is the rice/tree crop system located in Madagascar – mostly in the moist subhumid and humid zones – in which banana and coffee cultivation is complemented by cassava, legumes, maize and rice.

Since neither tree crop nor food crop failure is common, price fluctuations for industrial crops constitute the main vulnerability. Socio-economic differentiation is considerable, but growth potential is moderately high. The main trends affecting the system relate to population pressure on natural resources, declining terms of trade and market share, dismantling of parastatal input supply and marketing services, and withdrawal of the public sector from industrial crop research and extension.

Commercial largeholder and smallholder system (5 percent land area, 4 percent agriculture population in Sub-Saharan Africa)

This farming system extends across the northern part of the Republic of South Africa and the southern part of Namibia, mostly in semi-arid and dry subhumid zones. It comprises two distinct subtypes – scattered smallholder farming in the homelands and large-scale commercialized farming. Both subtypes are largely mixed cereal–livestock systems, with maize dominating in the north and east, and sorghum and millet in the west. Both cattle and small ruminants are raised. The level of crop–livestock integration is moderate. Vulnerability is high in the smallholder subsystem, since a considerable part of the farming system has poor soils and is drought-prone.

Coastal artisanal fishing system (1 percent land area, 1 percent agriculture population in Middle East and North Africa; 2 percent land area, 3 percent agriculture population in Sub-Saharan Africa)

Small-scale artisanal fishermen have worked the coasts of the Mediterranean and the Atlantic Ocean for thousands of years. As modern technology and capital have been injected into the offshore fishing industry, the artisanal fishing system has shrunk. In West Africa, the system stretches southward from The Gambia and the Casamance region of Senegal, along the coast of Guinea Bissau, Sierra Leone, Liberia, Côte d'Ivoire and Ghana, to Nigeria, Cameroon and Gabon. Population densities are average to high. Households dependent on lake and river fishing are not included in this system.

The system is based on artisanal fishing complemented by multi-storied tree crop gardens with root crops under coconuts and fruit trees. Artisanal fishing includes sea fishing from boats, seine net fishing from beaches, setting of nets and traps along estuaries and in shallow lagoons, and catching of crustaceans in mangrove swamps. Poultry and goats are the main domestic animals. Cattle keeping is rare due to tsetse infestation, and land preparation is by hand. Off-farm opportunities are connected with tourist resorts along the beaches and with large tree crop estates. In West Africa, because of the humid climate, there is more swamp rice and little or no cashew nut.

Irrigated farming system (2 percent land area, 17 percent agriculture population in Middle East and North Africa; 1 percent land area, 2 percent agriculture population in Sub-Saharan Africa)

Large-scale irrigation schemes have been linked primarily to perennial surface water resources notably in Egypt, Nigeria, Mali, Mauritania and Senegal. However, since the 1960s, the rise of drilling and pumping technology has permitted the development of large groundwater-dependent schemes. They are found across all zones and include high-value cash and export cropping and intensive vegetable and fruit cropping. Patterns of water use vary greatly, but often it is not used efficiently; and there have been significant economic and environmental ramifications from excessive drawdown of nonrecharged aquifers, and from excessive irrigation that has led to rising groundwater tables with soil salinization and sodication problems.

Small-scale irrigated systems occur in many places across the region and, although they may not be important individually (in terms of numbers of people involved or in the amount of food and other crops produced), they are a sig-



nificant element in the survival of people in dry areas. Such systems develop along small perennial streams and at oases, or are built where flood and spate irrigation is feasible, as well as around boreholes. The major crops are mixed cereals and vegetables. These locations (where water is available) always provide a focal point for socio-economic activity, but intense local competition for limited water resources between livestock owners and farmers is becoming increasingly evident. The hatching in Figure 3.1 denotes areas with substantial small-scale irrigation.

The irrigated farming system is thus quite complex. In many cases, irrigated cropping is combined with rainfed cropping or animal husbandry. It is also possible to distinguish between full and partial water control. Crop failure is generally not a problem, but livelihoods are vulnerable to water shortages, scheme breakdowns and deteriorating input/output price ratios. Major constraints include iron toxicity problems, scarcity and quality of water resources in dry regions and excessive water in humid zones.

Sparse (arid) system (62 percent land area, 5 percent agriculture population in Middle East and North Africa; 17 percent land area, 1 percent agriculture population in Sub-Saharan Africa)

This system covers the extensive desert areas of the region. It contains some oasis farming and a number of irrigation schemes (notably in Algeria, Libya, Morocco, Sudan and Tunisia) where dates and other palms, vegetables, and cereals such as maize and rice are grown. Crop residues provide opportunistic grazing for the herds of pastoralists, and other fodder grows after scattered storms and in good seasons. The boundary between pastoral grazing and sparse agricultural systems is indistinct. Constraints are those already described for the component systems (pastoral, agro-pastoral and irrigated).

Urban and peri-urban based system (less than 1 percent land area, 6 percent agriculture population in Middle East and North Africa; less than 1 percent land area, 3 percent agriculture population in Sub-Saharan Africa)

Within the estimated total urban population of over 200 million in the region, there are many farmers in and around cities and large towns – in some cities it is estimated that 10 percent or more of the population are engaged in urban agriculture. This farming system is very heterogeneous, encompassing small-scale but capital-intensive, market-oriented, commercial vegetable growing, horticulture, dairy farming and livestock fattening, and part-time farming by the urban poor to cover part of their subsistence require-

ments. But the level of crop-livestock integration is often low. There are some environmental and food quality concerns associated with urban farming, but overall this is a dynamic farming system that has considerable growth potential.

Highland mixed system (7 percent land area, 30 percent agriculture population in Middle East and North Africa)

There are two subsystems in this category that are sometimes interlocking. The first is dominated by rainfed cereal and legume cropping, with tree crops like coffee, fruits, olives, and qat, as well as vegetable crops planted on terraces, sometimes with supplementary irrigation in the summer months for crops such as melons or high-value fruits. The second system, based on livestock (mostly sheep) on communally managed lands, involves several countries. In some cases, livestock, and the people who control them, are involved in a transhumance system, migrating seasonally between lowland steppes in the more humid winter season and uplands in the dry season. Such systems exist in Morocco. Wheat and barley dominate these systems that are generally monoculture with occasional fallows. Surrounding these cropped areas are common grazing lands, which may be used by owners from the same region or by pastoralists migrating to the plains for the winter season.

Major constraints are the decline in the natural resource base through reduced maintenance of terraces and productivity losses from increasing water erosion. Some other problems are emigration to urban and plains areas, decline of soil fertility through continuous cropping, overuse of ground water, and low nutrient return. Increased competition from subsidized imports of meat and dairy products continues to impoverish small producers.

Rainfed mixed system (2 percent land area, 18 percent agriculture population in Middle East and North Africa)

The crops in this system are primarily rainfed, although in some areas supplementary irrigation on wheat and full irrigation for summer cash crops are developing rapidly. There is some dry-season grazing of sheep migrating from the steppe areas. There are tree crops (olives and fruit trees), melons and grapes. There is also some protected cropping with supplementary irrigation for flowers, potatoes, sugar beet, vegetables and specialist crops. In the more humid areas there are few trees apart from more drought-resistant ones. Common crops are barley, chickpeas, lentils, wheat and fodder crops such as vetches and medics. Some supplementary irrigation may be used for vegetable and cut-



flower production. Many farms are intensively capitalized with a high level of inputs, and farmers are very sensitive to market opportunities. There are a number of specialized dairy and poultry systems within this ecological zone. These may also include summer crops grown following winter fallow or with some supplementary irrigation. Major production constraints are poor access to quality land by increasing numbers of small farmers, soil erosion on slopes during rainstorms, and erosion by wind on light, over-cultivated, exposed soils.

Dryland mixed system (4 percent land area, 14 percent agriculture population in Middle East and North Africa)

This system is in the dry subhumid area where the main rainfed cereals are barley and some wheat with annual or two-year fallow. Occasionally legumes (chickpeas and lentils) may be grown in higher-rainfall areas. Interactions with pastoral systems are strong as sheep may graze whole-crop barley in a dry year and the stubble of the harvested crop in average or wetter years after the end of the cropping period. Small areas of irrigated vegetables may be grown in association with these systems. Rainfed barley is grown as a whole-crop fodder or, in good years, for both grain and fodder. Cropping is highly dependent on rainfall, and the whole system is vulnerable to inter-annual and seasonal rainfall variations. In the recent past, there has been a decline in wheat area and renewed use of indigenous barley varieties. The most critical issue appears to be limited access to new crops and varieties. Some of the more arid areas with lighter soils have severe wind erosion problems during the dry season. Overgrazing is also a problem.



Agricultural productivity trends

The farming systems described and characterized in Box 3.2 evolve and develop continuously, aiming at higher productivity, continuity and greater efficiency. Figure 3.2 illustrates changes in productivity per hectare over a 40-year period. The outcomes of science and technology may be reflected as changes in agricultural productivity, where productivity is expressed as returns from employing the factors of production – land, labour and external inputs such as nitrogen and phosphate. Productivity can be evaluated at different levels of aggregation, from crop, farm and agro-eco system level up to global level. For the purposes of this study the land productivity at the farming systems level is examined, but with sparse data for labour and input use in some cases only by way of illustration.

Agricultural production statistics databases for Africa (e.g., the agricultural statistics database, FAOSTAT) usually provide data only at the national level; therefore it is necessary to disaggregate the country data to the farming systems level. The farming systems distribution maps of Dixon and colleagues (2001) were used to estimate the proportion of the land area of each African country that falls within a farming system. Next, countries were selected that had 50 percent or more of the land area within a farming system. It is expected that the higher the proportion of a country that falls within a given farming system the more representative its national production statistics would be of trends within that farming system. One disadvantage is the omission of data for Nigeria from this analysis. In this case, all farming systems occupy less than 50 percent of the country's total crop area, thus the increased yields of maize grown in the savannah (cereal/root crop mixed system) during the 1980s and 1990s are not reflected in the system's trends (Smith et al., 1994). The irrigated system also presents a special case – a limited proportion of agricultural land area is irrigated in all countries except in Egypt, where all agricultural land is irrigated. Thus only Egypt is represented in the analysis of productivity trends in the irrigated farming system. Also, productivity trends for some crops in the sparse (arid) farming systems are strongly influenced by the fact that they are cultivated in irrigated systems. All farming system averages are weighted by crop area.

Changes in yields (land productivity) for several major farming systems using five-year averages from 1961 show the following general patterns:

- Root crop yields have grown modestly in farming systems in which they are the principal commodities (e.g., cassava in the tree crop-based, forest-based and maize mixed systems, yam in the cereal/root crop mixed



system, and cocoyam in the forest based system). There has been hardly any growth in yields where these commodities are grown as secondary crops in the farming system (e.g., in the agro-pastoral or highland perennial systems).

- Cereal crop yields (maize, millet, sorghum, rice and wheat) have grown significantly in the irrigated and commercial farming systems.
- Rice is the only cereal whose yields have increased consistently in other farming systems, especially since the mid-1980s. But the increases have been modest in the farming systems in the humid zones (tree crop based, cereal/root crop mixed) where most of the rice is grown under rainfed conditions. The growth in the sparse (arid) and agro-pastoral systems reflects the fact that rice is grown mainly under irrigation in those systems.
- The trends in cereal crop yield generally show a slight drop in the second half of the 1980s and 1990s, especially for maize.
- The effect of civil conflict on agricultural productivity is illustrated in the dramatic decline in crop yields since the 1980s in the highland perennial farming system (Rwanda and Burundi), especially for the food security root crop, cassava.
- The steady increase in yields over the last decades has not kept pace with the population growth in all regions of Africa. Since the expansion of agricultural area was also limited, per capita food productivity declined, with a consequent decrease in food security.

Major discontinuities in the increase of agricultural productivity per hectare occurring in the Western world in the 1950s and in Asia in the 1970s – Green Revolutions – did not occur in Africa. These Green Revolutions occurred in farming systems dominated by rice, wheat or maize. In Africa such dominating systems are minimal, as demonstrated earlier.

A range of factors underlies the productivity trends described above. In this chapter factors that impact yield across the major systems are studied. Chapter 4 describes more closely the specific technical constraints that limit productivity of the dominant crops in the priority systems and that research must address over the next 10-15 years to contribute to the achievement of the UN Millennium Development Goals.

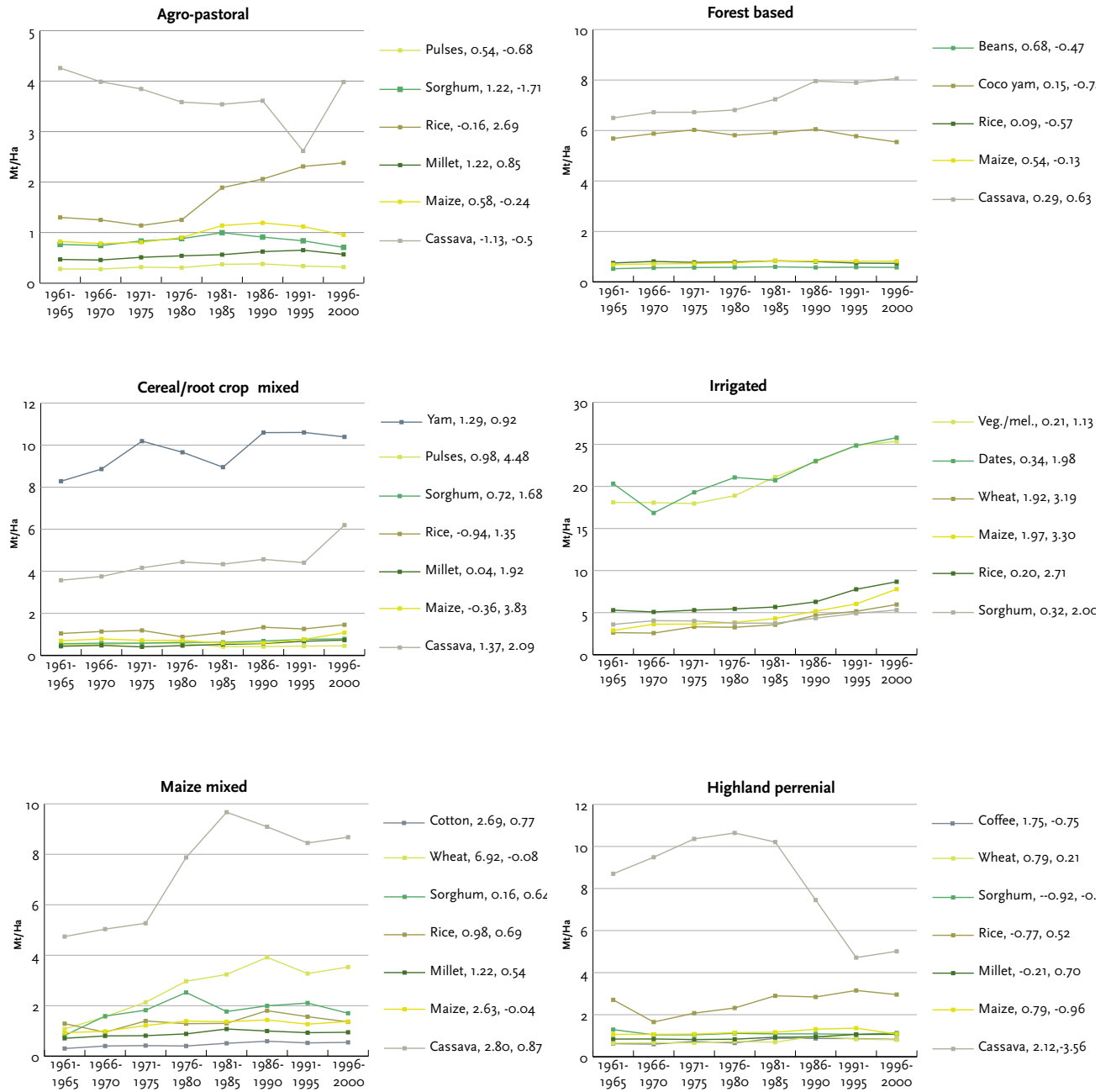
The production ecological approach

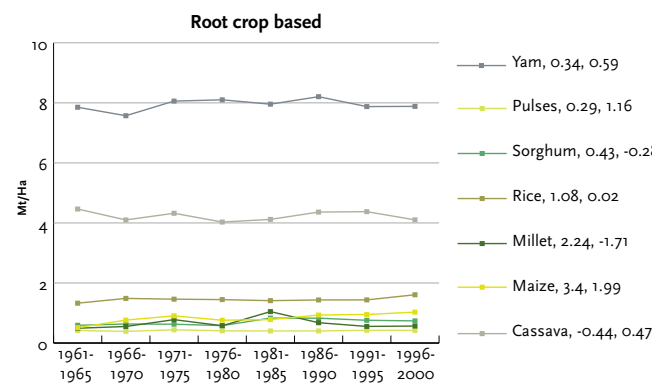
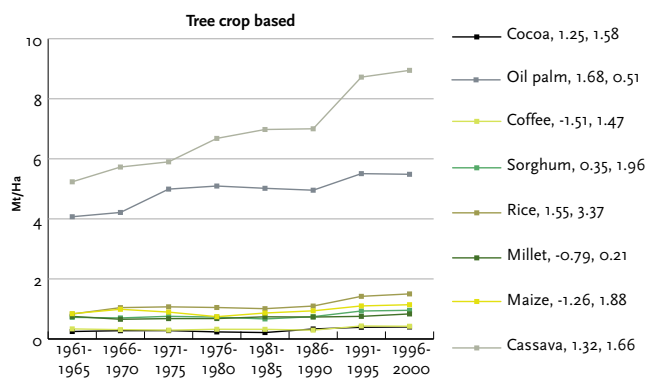
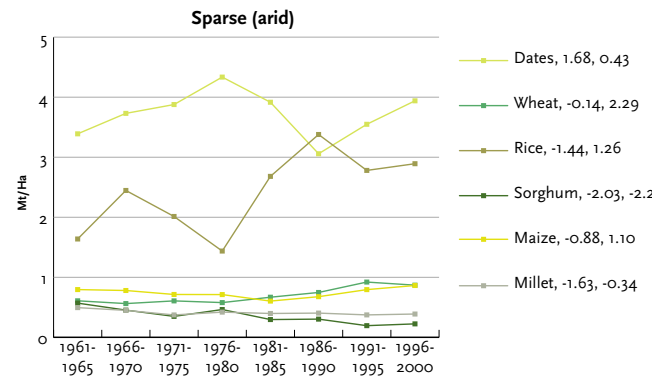
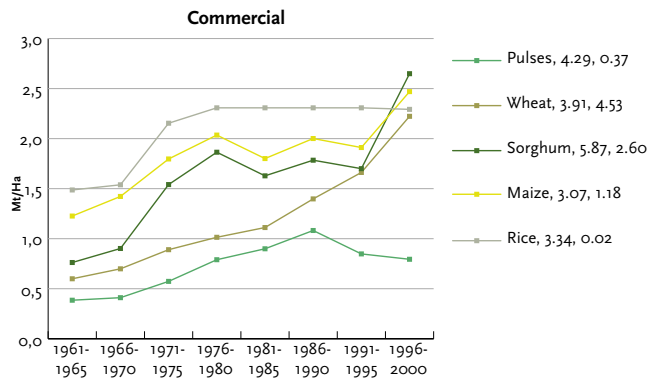
A production ecological approach disentangles *growth- and yield-defining factors* (genetic potential and solar radiation), *growth- and yield-limiting factors* (water and nutrients), and *growth- and yield-reducing factors* (weeds, pests, and diseases) in agricultural-production systems. This approach



Figure 3.2 Land productivity trends of the major commodities in African farming systems

Source: FAOSTAT (2003). The numbers in the legend refer to the average percentage of annual yield increase in the period 1961-1980 and 1981-2000, respectively.







Box 3.3 Systematically disentangling factors that affect growth and yield

Applying the production ecological approach in long-term research program in the 1970s revealed the counterintuitive result that agricultural production in the Sahelian region was not limited primarily by drought, but by poor soil fertility. These findings are illustrated graphically showing the effect of the relative availability of radiation, water, nitrogen and phosphorus on growth of annual grasses in the Sahel (See Figure 3.3). The shaded area represents the zone of actual crop growth; the non-shaded area below the horizontal line represents the growth that can be obtained without limitations. Water sets a limit to the growth rate after germination, the low availability of phosphorus for some times afterwards, while the availability of nitrogen

limits growth at the end of the season. Hence, nutrients rather than water set the strongest limit to growth. Under actual conditions, growth may even be further reduced due to pests and diseases. This concept is generally applicable for crop growth. An increasing number of field experiments confirm that nutrient limitations set a stronger ceiling to yield than water availability in numerous semi-arid regions, including those in the Mediterranean (French and Schultz, 1984), eastern Africa (Smaling et al., 1992), Sub-Saharan Africa (Rockström, 2001), the Sahel (Breman et al., 2001), southern India (Ahlawat and Rana, 1998), and western China (Li et al., 2001).

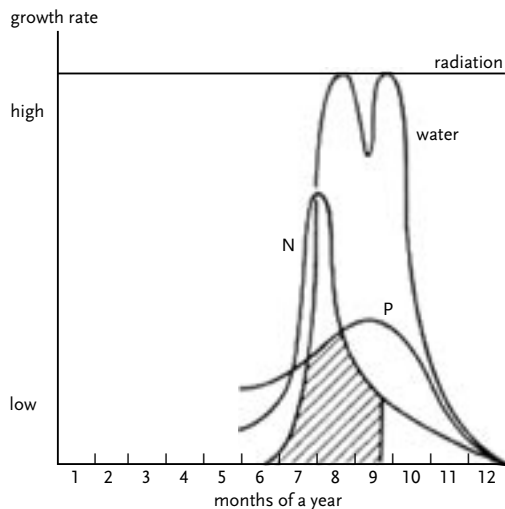


Figure 3.3 The relative impact of radiation, water, nitrogen and phosphorus growth of annual grasses in the Sahel. The graph is a schematic representation based on field observations.



allows for more comprehensive identification and prioritizing of agro-ecological constraints while helping to recognize technological opportunities for improvement.

The production ecological approach is a method for systematically studying the integration of basic physical, chemical, physiological, and ecological processes (Ittersum and Rabbinge, 1997). To understand, for instance, the growth performance of crops or animals, it is important to study not just the growth (i.e., biomass accumulation) itself but the processes that generate growth – such as the absorption of radiation, the photosynthetic production of carbohydrates, and the conversion of carbohydrates into proteins, fats, lignin and other components.

Systematic analysis of these underlying eco-physiological processes has improved the understanding of the dynamics of plant and animal behaviour to the point that the relative importance of growth and yield factors and inputs to productivity may be identified. This in turn presents opportunities for improving productivity and evaluating the effectiveness of new technologies and input measures. The approach has thus facilitated communication among various disciplines in agricultural science, thereby allowing comprehensive analyses of agricultural systems. This ability is illustrated in Box 3.3. A systematic categorization using production ecological analysis distinguishes four production levels (Figure 3.4):

- Crops are grown under optimum conditions and therefore realize their potential production level. Growth is determined by crop-genetic characteristics and the prevailing environmental factors of radiation, temperature, atmospheric carbon dioxide concentration, and day length. Management ensures adequate supplies of water and nutrients, and crop protection.
- Crops are grown under water-limited or nutrient-limited conditions – that is, insufficient water or nutrients are available to meet their optimal needs – and they reach attainable production levels.
- Crop growth is further reduced because of the adverse effects of pests, diseases, weeds, or pollutants, with consequent reduction in yield.
- The available food is reduced by up-stream chain effects of which post-harvest loss is a major component.

The potential yield can be influenced by manipulation of radiation, temperature and carbon dioxide levels only under controlled conditions, such as in greenhouses and stables. Growth- and yield-limiting and growth- and yield-reducing factors can be influenced by agronomic practices under field conditions. Measures range from fertilization and irrigation to protec-

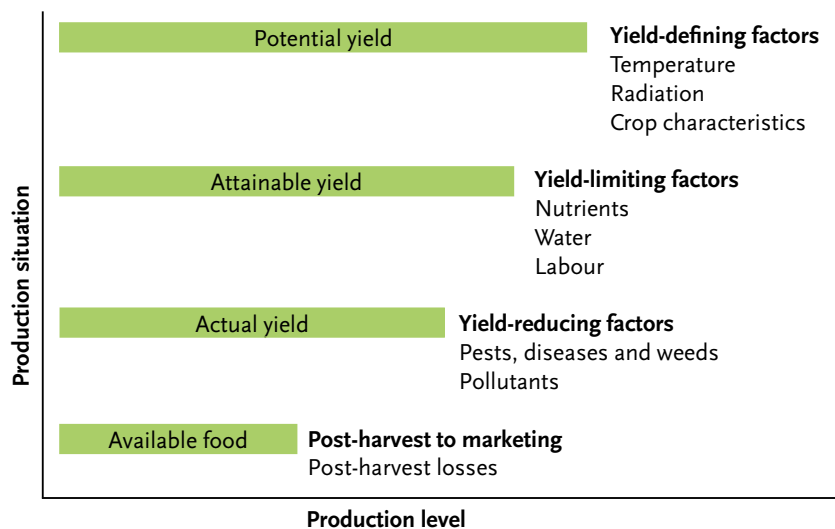


Figure 3.4 Principles of production ecology and factors affecting growth and yield and food availability. The graph represents technical constraints. The actual input levels will be determined by economic considerations.

tion with biocides against pests, weeds and diseases. Genetic improvement can affect crop performance under all production conditions. The yield potential of cereal crops has, for instance, been increased through improving allocation to desired parts (i.e., the grains, resulting in increased harvest index). Genetic adjustments can also aim to enhance use efficiencies of nutrients and water, improve ability to take up water and nutrients and increase resistance or tolerance to drought, certain diseases or pests.

Applying the production ecological approach, estimates can be made of yields that can be obtained under various ecological conditions. Also, the impact of management practices, such as fertilizer application or irrigation on yield can be assessed, revealing trade-offs and synergies of input use. Whether or not required inputs will be actually applied by farmers depends on socio-economic conditions, in particular market access and input-output price ratios. Yield assessments using the production ecological approach facilitate yield gap analysis, which has been elaborated in Box 3.4.

The strength of the production ecological approach is its ability to differentiate among the individual and combined effects of the various production factors on yields. Understanding these synergies is of fundamental importance to the development of management and cultivation strategies to enhance productivity. This aspect is elaborated in Box 3.5.



The need to develop the production ecological approach has emerged from the urge to explain the behaviour of living or biological systems. Statistical analyses will reveal differences observed in experimental fields, but these ex post analyses lack the ability to explain those differences. For that, it is necessary to understand ‘underlying processes’ that govern the observed factors. For instance, to understand growth, the processes of photosynthesis and maintenance must be described. The insight gained of the

Box 3.4 Yield gap analysis

Yield gap analyses are used to identify opportunities for productivity increases (Figure 3.5). Yield gaps are most commonly expressed as the difference between actual farm yields with yields obtained on experimental fields (YG1). Other ways of expressing yield gaps are the highest yield levels of the best farmers versus yields of average farmers (YG2), differences between countries with higher and lower yields, and so on (FAO, 1999). Yield gaps based on production ecological principles are of a different nature. The gaps are based on

theoretically calculated yields that can be obtained under potential (YG-Potential) or attainable production conditions relative to actual farmers’ yields. Generally potential yield assessments are higher than yields obtained in experimental fields, as growth conditions even under experimental conditions may not be optimal. Though the gaps may seem theoretical, they are based on eco-physiological processes and provide guidance to researchers as to how to further improve agronomic practices for optimizing growth conditions.

The principal difference between the two approaches in expressing yield gaps is the lack of explicit identification of the relative and absolute impact of production factors. While experimental yields may be seen as the highest yields feasible, still unidentified factors may suppress the performance of the crop. These factors cannot be identified without thorough, in-depth analyses based on eco-physiological principles. The two methods are therefore complementary.

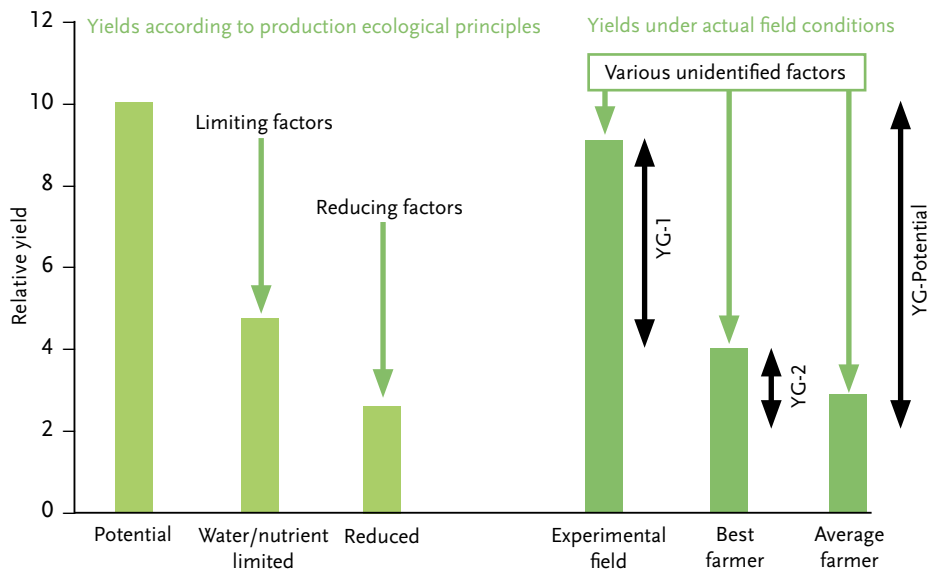


Figure 3.5 Yields analyzed according to production ecological principles and under actual field conditions.



Box 3.5 Best technical means

The untapped production reservoir available promises opportunities for improvements (Swaminathan, 1999). The production ecological approach recommends deployment of agronomic measures that utilize the entire arsenal of technologies to maximize potential productivity increases. The combined use of inputs results in synergies that enhance use efficiency and reduce environmental burden (De Wit, 1992, Breman et al., 2001). They provide options that can be catered to specific situations.

For Africa, yields can be increased with the application of a broad package of agronomic measures, while yields can decline in areas where a single measure such as mechanization is introduced (Ahmed et al., 2000; Ahmed and Sanders 1998). An over-reliance on a cultivar-alone strategy, such as the introduction of improved sorghum or millet varieties, also gives limited gains (Ahmed et al., 2000).

Breman and colleagues (2001) illustrate that the recovery of nutrients is related to the levels of other resources (Figure 3.6). At very low levels of soil fertility nu-

trient recovery is low and improves exponentially when soil improvement is attained by using applied nutrients. Under well-endowed conditions, either natural or created through improved management, the highest efficiencies can be obtained. Apparently, any decrease in marginal returns of increased fertilizer use can be compensated for by benefits from other eco-technological changes. De Wit (1992) demonstrated that the law of diminishing returns indeed does not hold for yield versus nitrogen application when comparing yield developments in various regions around the world historically. Of course over time other factors affecting yield have improved as well, but to different degrees in different countries.

Hence yield-fertilizer response functions would have lifted, but at various rates. Plotting yields versus nitrogen application rates across countries under these circumstances results in a different relationship than when other factors are held constant. The production ecological approach aims to capture these multiplicative effects.

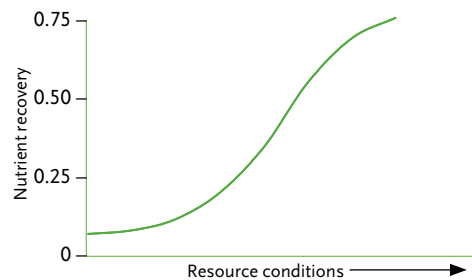


Figure 3.6 Schematic relation between nutrient recovery and agro-ecological conditions.



impact of these basic processes on systems behaviour allows us to better influence the course of living processes, such as crop growth and yield. Crop growth models that explain growth and yield therefore include a large number of basic physiological processes. Over time, soil processes and the influence of pests, diseases and weeds have been incorporated. The complexity of the models increases as more processes and factors are considered. In principle, yield decreases with an increasing number of factors affecting growth, as has been elaborated in Figure 3.4.

The production ecological approach therefore demands an integrated approach from a wide range of biophysical disciplines. It has increased the need for improved communication and exchange of information among disciplinary scientists, including socio-economists. Obviously, this approach requires new skills and changes the mind set of scientists who need specific training to effectively implement the production ecological approach. Not surprisingly, the approach has significantly affected the research and education agenda at various advanced research centres around the world, in particular Europe, North America, Australia and Asia (Pening de Vries et al., 1993; Bouma et al., 1994; Teng et al., 1997). The power of the approach is illustrated in the report, *Method in our Madness*, by the International Service for National Agricultural Research (ISNAR) in which three African case studies are described. In these studies, African national agricultural research institutes (NARIS) in Kenya and Tanzania have been actively involved (ISNAR, 2004).

The production ecological approach has been implemented in a number of areas. Various decision support systems at operational, tactical and strategic levels are operational. Instigated by the concern for the environment, the search for more efficient use of natural resources at the field level has been intensified, leading to a fine tuning of crop demand and supply in time and space for supporting operational measures (e.g., Ten Berge et al., 1997). Minimizing the application of chemicals in pest, disease and weed control have reduced the use of agrochemicals. Tactical decision information has been derived from analyses that search for optimal planting dates to maximize production or to escape drought or diseases. At increasing aggregation levels, farming and land use systems analyses can be used to optimize resource use. The systems approach is increasingly being used to design entire farming systems that comply to economic, as well as to ecological and social desires. Analyses for policy support on regional land use planning or on global food production seeks to optimize seemingly conflicting desires, such as on nature conservation and food production



through multiple goal linear programming techniques (WRR, 1995; Ittersum et al., 1998). This concise overview illustrates that the production ecological approach provides fundamental support to systems analyses at various aggregation levels.

Growth- and yield-defining factors

GENETIC TRAITS

High-yielding varieties of a many different crops are commonly grown throughout the world. These varieties have been the key to a dramatic increase in yield, and formed the heart of the Green Revolution in Asia. The increase in harvest index (grain: total biomass ratio) from 0.3 to 0.5 caused this change. Furthermore, better growing conditions created more growth and therefore more total biomass. The full productivity rise due to these two major changes is only achieved in optimal growing conditions, eliminating the effects of growth- and yield-limiting and growth- and yield-reducing factors. When these prerequisites cannot be met, well-adapted landraces that may be less affected by the growing conditions are often less risky and preferred.

The proportions of farmers' fields planted with improved varieties in 1998 in Africa were around 40 percent for rice, 17 percent for maize, 26 percent for sorghum and 18 percent for cassava. Except for cassava, these were lower proportions than in Asia (about 65 percent for rice, 70 percent for sorghum) and Latin America (about 65 percent for rice, 46 percent for maize, 7 percent for cassava) (Evenson and Gollin, 2001). Until recently, the Green Revolution research paradigm in Africa has resulted in productivity gains mainly in farming/production systems that are most similar to the major cropping systems of Asia – namely the irrigated rice-wheat systems.

In Africa, where few farmers have access to either irrigation or affordable chemical inputs, and where growth- and yield-reducing factors contribute to large pre- and post-harvest losses, farmers' actual yields are typically a fraction of the genetic potential, even for their current varieties (De Jager et al., 2001). In this situation, research may be more efficiently directed at closing the yield gap by focusing on growth- and yield-limiting and growth- and yield-reducing factors. This research needs to address both technical and economic aspects. Technology-driven options require the development of varieties with properties such as salt tolerance and resistance to the prevailing pests and diseases. Moreover, given the diversity



of production environments and farming systems, crop improvement research needs to use agro-ecological approaches that develop new varieties to fit into local niches, placing a premium on farmer participatory approaches (DeVries and Toenniessen, 2002). Research also needs to be directed at understanding and resolving factors that limit access to fertilizers, that make fertilizers use more efficient and that make irrigation more appropriate and less costly for small farmers. The latter research agenda includes work on technical, institutional and policy measurements and are addressed in further chapters.

CLIMATE AND WEATHER

The productivity potential of crops in Africa is quite high due to solar radiation and high temperature. Incoming radiation and temperature were once factors unaffected by humans, but that has changed in the last century. Scientific evidence on global warming points to a rise in average temperatures of 1.4-5.8°C over the next century (Wilson, 2001). A sustained increase in mean ambient temperatures beyond 1°C will cause significant changes in forest and rangeland cover, species distribution and composition, migration patterns and biome distribution. The African continent is particularly vulnerable to the impacts of climate change because of widespread poverty, inequitable land distribution, and high dependence on rainfed agriculture (IPCC, 2001). Most models predict more frequent and severe extreme weather events in the tropics generally, including both localized drought and flooding. Some drought episodes, particularly in southeast Africa, are associated with El Niño-Southern Oscillation (ENSO) phenomena, which have occurred more frequently in the last several decades.

Arid and semi-arid subregions and the grassland areas of eastern and southern Africa, as well as areas currently under threat from land degradation and desertification, are particularly vulnerable to global warming. A reduction in rainfall projected by some climate models for the Sahel and southern Africa, if accompanied by high inter-annual variability, could be detrimental to the hydrological balance of the continent and disrupt various water-dependent socio-economic activities. Variable climatic conditions may render the management of water resources more difficult, both within and between countries.

The productivity of coastal waters is dependent on ocean processes like upwelling, the health of mangrove forests, coral reefs, and seagrass beds and the amount and quality of runoff from the rivers. The western side of



Sub-Saharan Africa includes some of the important upwelling ecosystems in the world. The wealth of estuaries, deltas, coastal lagoons, and coral reefs also contribute significantly to the diversity of fish life in the region (Koranteng, 2003).

Higher temperatures will also be accompanied by rising sea levels and more frequent occurrences of extreme weather events, such as flooding, droughts, and violent storms, causing changes in agricultural practices. Several African coastal zones, some of which already are under stress from population pressure and conflicting uses, would be adversely affected by sea-level rise associated with climate change. Of particular concern are the coastal zones of Angola, Cameroon, Gabon, The Gambia, Nigeria, Senegal, and Sierra Leone. Studies also indicate that a sizable proportion of the northern part of the Nile Delta could be lost to agriculture through a combination of inundation and erosion.

Climate change has particularly exacerbated soil degradation in the dry areas – pastoral, agro-pastoral, and sparse (arid) systems. Prolonged drought has already led to several ecological consequences, including (a) elimination of grass cover in some areas; (b) elimination of some bushes and acacia stands with shallow roots; (c) drop in the groundwater table, especially near wells and watering holes; (d) an increase in shifting sands; (e) increased wind erosion of fine soil components; and (f) increased evapotranspiration, accompanied by drying or cracking of soils (Oldeman, 1999). Recent evidence suggests that rainfall variability may be a more important determinant of the health of a rangeland and its soils than overgrazing (UNEP, 1997).

Growth- and yield-limiting factors

Crop growth and yield are limited through poor plant nutrition and uncertain water availability during the growing cycle. Inappropriate management driven by poverty may worsen the condition of the old weathered and overworked soils of the African continent, further reducing their fertility. In many places in Africa, fields, farms and regions suffer from the absence of sufficient resources to invest in soils and to improve the growing conditions. As a consequence, farmers are caught in a spiral of unsustainability (Rabbinge, 1995).



SOIL FERTILITY AND PLANT NUTRITION

Land degradation can take a number of forms, including nutrient depletion, soil erosion, salinization, agrochemical pollution, vegetative degradation from overgrazing and the cutting of forests for farmland (Scherr and Yadev, 2001; Lhoste and Richard, 1993). Twenty-six percent of the degraded soils in Africa (128 million hectare) are classified as being strongly or extremely degraded, meaning that the terrain would require major investments and engineering works for reclamation, or is irreclaimable (5 million hectare). Overgrazing is the most important cause of soil degradation, accounting for 49 percent of the area, followed by agricultural activities (24 percent), deforestation (14 percent) and over-exploitation of vegetative cover (13 percent). All these forms of degradation cause a decline in the productive capacity of the land, reducing attainable and potential yields (Lamachère and Serpanié, 1991; Casenave and Valentin, 1992).

Depletion of soil fertility is a major biophysical cause of low per capita food production in Africa (Pieri, 1989; Rabbinge, 1995; Breman et al., 2001; Sanchez, 2002). Smallholders have removed large quantities of nutrients from their soils without applying sufficient quantities of manure or fertilizer to replenish the soil. This has resulted in a very high average annual depletion rate – 22 kilograms of nitrogen, 2.5 kilograms of phosphorus and 15 kilograms of potassium per hectare of cultivated land over the last 30 years in 37 African countries – an annual loss equivalent to us\$4 billion in inorganic fertilizer.

Fertilizers have been applied to counteract loss of nutrients. Productivity trends demonstrate that the benefits of science and technology in Africa have been captured most consistently in the commercial and irrigated farming systems where purchased inputs are used most extensively (Figure 3.7). In the more traditional upland rainfed farming systems there has been some limited success with root crops, especially in systems where cassava is the principal crop. However, as demonstrated in Figure 3.7 and in Box 3.5, at the very low levels of soil fertility the efficiency of use of external resources is extremely low. This and the often poor input-output price ratios and difficulties with market access are major contributors to low input use.

WATER AVAILABILITY

The vast majority of farming systems in Africa is rainfed and only a small area is irrigated (Table 3.3). The possibilities for full and supplementary ir-

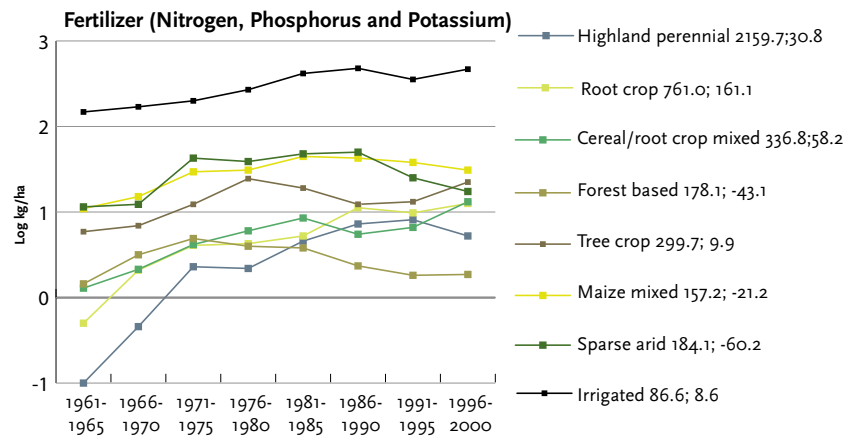


Figure 3.7 Trends in the use of fertilizers in farming systems in Africa.
 Note: Figures in the legend represent total percentage change in fertilizer use for two periods – 1961/65-1976/80 and 1981/85-1996/2000). Source: FAO (2003)

rigation are limited. In 1995, 96 percent of cereals in Sub-Saharan Africa were sown in rainfed agricultural systems (Rosegrant et al., 2002). Only four percent was irrigated. Because yields in rainfed systems are lower than in irrigated ones, 89 percent of cereal production in the region was derived from rainfed agriculture. These proportions are not expected to change significantly in baseline projections to 2021-25 (Table 3.4). Only soybean has and will continue to have most of its production derived from irrigated agriculture.

With the exception of Egypt, most of North Africa grows rainfed crops. Unfortunately data for North Africa are not readily available, only for West Asia and North Africa combined. These show that in this region, with the exception of maize, cereal production will continue to be dominated by rainfed systems, even towards 2025.

Future rainfed agricultural strategies in Sub-Saharan Africa should emphasize sustainable yield increases rather than area expansion, the latter being the dominant factor involved in increasing production in the past. Expanding cultivated areas will reduce fertility-enhancing fallow periods, leading to further reductions in soil fertility, erosion, land degradation and loss of biodiversity. The integration of crop and transhumance livestock production can also be impaired when expanded cropland impedes the free movement of grazing livestock during the rainy season.



Table 3.3 Irrigated land in farming systems in Africa in 2000

Farming systems	Agricultural area (1,000 ha)		
	Land use	Irrigation	Percent irrigated
Cereal/root crop mixed	62,874	163	0.26
Highland perennial	3,890	79	2.03
Maize mixed	108,629	360	0.33
Root crop	11,525	37	0.32
Forest based	38,594	27	0.07
Tree crop	49,289	182	0.37
Agro-pastoral	8,050	71	0.88
Sparse (arid)	111,395	1,145	1.03
Large commercial	99,640	1,498	1.50
Irrigated	3,291	3,291	100.00
Africa total	1,101,166	12,680	1.15

Source: Compiled from FAO (2003).

Table 3.4 Proportions of rainfed areas and production totals in 1995 and projected to 2021-25 in Africa

Region/commodity	Percentage rainfed			
	Area		Production	
	1995 actual	2021-25 baseline projection	1995 actual	2021-25 baseline projection
Sub-Saharan Africa				
Total cereals	96	95	89	89
Rice	81	77	68	64
Wheat	78	75	73	71
Maize	96	96	90	90
Soybeans	25	27	49	52
West Asia/ North Africa				
Total cereals	78	77	58	55
Wheat	81	81	63	59
Maize	36	27	16	12

Source: Rosegrant et al. (2002: 57-58, 74-75)

Sustainable intensification strategies for rainfed systems require improved integrated soil, water and nutrient management innovations. As discussed in Chapter 4, these include run-off management, water harvesting and supplementary irrigation, conservation tillage, organic and inor-



ganic fertilizers, and integration of more leguminous species into rotation systems. There is increasing evidence from Asia that research and development (R&D) investments in rainfed areas offer win-win outcomes, in terms of both productivity growth and reductions in poverty, far in excess of similar investments in irrigated agriculture (Fan, Hazell and Thorat, 2000; Fan, Hazell and Haque, 2000; and Fan, Zhang and Zhang, 2002). Yield gaps in rainfed areas are often higher than in irrigated areas and hence the returns from further R&D and infrastructure investments can be higher.

In rainfed systems, it can be shown that soil fertility is the most limiting factor (Sanchez, 2002). As a consequence, the effect of increased water availability through irrigation is limited and depends on the soil fertility in these systems.

Although only a small component, irrigation plays a major role in some systems. Productivity increases have been significant and consistent over the past five decades in these irrigated farming systems. Some observers have argued that the full potential of irrigation in Africa is far from being adequately exploited; pointing out that the 12.7 million hectare under irrigation is only 30 percent of the 42.5 million hectare of the potentially irrigated land. However, several observations must be made with regards to tapping that potential (FAO, 1997):

- Over 60 percent of the irrigation potential is located in the humid regions and almost 25 percent in the Congo Basin alone. These are the regions where the potential for rainfed agriculture is also high and where irrigation is mainly supplementary.
- In the regions where irrigation is important for agriculture, over 60 percent is already irrigated, including most of the areas with the best potential and lowest costs. New developments will therefore typically require higher investments in terms of water regulation or transportation, or will take place on less productive soils. Investment costs for new irrigation schemes in Africa can be substantial, varying between us\$5,000 and us\$25,000 per hectare, and are on average much more expensive than similar investments in Asia.
- Over 50 percent of the areas currently under irrigation need rehabilitation if they are to achieve their sustainable potential. Innovative approaches are needed to avoid the same failures in the future, with an accent on smaller and more flexible water management systems and greater participation of farmers in irrigation systems design, management and maintenance.
- Many successful irrigation projects in various regions in the world are based upon alluvial soils. These soils are rare in Africa beyond Egypt.



Soils are hence inherently less conducive for both small- and large-scale irrigation development in Africa than in areas such as South Asia, and hence irrigation may not have the same impact as in other regions of the world.

The implication of water scarcity for much of Africa, especially in semi-arid farming systems, is that more water-efficient farm management systems will be needed. They will incorporate drought-tolerant varieties, choose species with higher water use efficiencies, and use crop and simulation modelling for increased water use efficiency, but they still will not be sufficient. Countries will need to devote more resources to increasing the supply of water. The size of investment to go into increasing water supplies relative to investment in development of new technologies will depend on the relative costs and chances of success (Ryan and Spencer, 2001). Most of the additional investment should not be in classic large-scale irrigation systems. There is considerable potential for capturing rainfall through improved soil surface management practices, small water harvesting systems and small-scale irrigation systems, enabling intensification of farming and crop diversification in inland valleys, and in upland systems using supplementary irrigation of high-value rainfed crops.

Growth- and yield-reducing factors

In all farming systems there are major factors that reduce crop growth. This also holds for animal production systems. Pests, diseases and weeds are a problem in nearly all farming systems of importance.

In Africa, many pests and diseases are known to occur and seriously threaten the productivity of major crops in some areas. Yield losses of up to 50 percent are mentioned for cassava: Cassava Mosaic Disease (CMD) can completely destroy a crop in heavily infected areas. Major pests of maize include stem and ear borers; armyworms; cutworms; grain moths; beetles (weevils, grain borers, rootworms, and whitegrubs) and virus vectors (aphids and leafhoppers). Major fungal diseases also affect maize. Ear rot, caused by *Fusarium verticillioides*, decreases yield but – more importantly – can produce mycotoxins that threaten human and animal health. Combined attacks by pests and weeds can severely damage cowpea plants and cause losses as high as 90 percent. Bananas are also vulnerable to diseases, especially panama disease (*Fusarium oxysporum* f.sp. *cubense*) and black Sigatoka leaf spot disease. The latter may reduce yield in banana and plantain by up to 40 percent. Even higher losses are reported for plants infected with banana streak virus (IITA, 2003).



A major pest in maize in Sub-Saharan Africa is witchweed (*Striga*). In the Nigerian savannah, for example, weed-related yield losses ranging from 65 to 92 percent have been recorded. Also crops like sorghum, millet and cowpeas are infested. Depending upon the extent of infestation, reductions in per hectare grain yield of 30-60 percent are common. A good method of estimating grain loss in an infested field is 3-4 kilograms per 100 *striga* plants per hectare for sorghum and 5-6 kilograms per 100 *striga* plants per hectare for maize, the lower number being used for fields or areas with less productive potential (Shank, 2003).

In Africa, the possibilities for chemical control of pests and diseases are restricted, due to the limited availability and high cost of pesticides. As a consequence, farmers in most farming systems have to find alternative solutions. The choice of resistant varieties is one of the most powerful tools, whenever appropriate varieties are available. Genetic modification offers a new tool for developing resistant varieties. To date, genes conferring resistance to pests and diseases have been transferred to certain target crops from a wide range of sources, far exceeding the limits set by the fertility constraints of conventional breeding. Although this is a powerful technique, it has not yet been applied to its full potential in many parts of the world, including Africa. Chapter 4 will discuss this topic in more detail.

Intrinsic properties of the farming systems themselves may limit damage caused by pests and diseases. In many Western countries, interest in intercropped farming systems is increasing because they demonstrate a higher buffering capacity against diseases, as demonstrated by Zhu and colleagues (2001) for rice in China. Therefore the complex intercropping systems used in Africa may be appropriate to limit the effects of diseases. This may reflect the use of indigenous knowledge by African farmers and needs further research.

Losses in other parts of the production-market chain

The primary production of crops and animals forms the first step in the chain from the soil to the ultimate consumed product. Much of the produced food is lost in post-harvest processes. This may be one of the major loss factors for food production in Africa. Although post-harvest losses are acknowledged broadly, it is difficult to estimate the actual damage. Amleson (2004) reports losses in African countries ranging from 10 to 100 percent. The FAO (1989) estimates the post-harvest losses of food grains in the developing world at 25 percent. Fruit, vegetables and root crops are much less hardy and can quickly perish. Consequently, they are much more vulnerable to decay than grains. Even moderate decay may render them un-



suitable for human consumption, or at least reduce their commercial or nutritional value. Some authorities put losses of sweet potatoes, plantain, tomatoes, bananas and citrus fruit up to, at times, 50 percent, and some crops can even be destroyed completely. Reduction in this wastage, particularly if it can economically be avoided, would be of great significance to growers and consumers alike.

Various factors, differing from region to region, from system to system and from commodity to commodity may affect post-harvest losses. Losses will be less in typical subsistence agriculture than in commercial farming. The latter requires higher standards since more handling is needed and the product must meet higher quality standards. The most important factors in post-harvest loss are harvesting and field handling, on-farm storage, packaging, transport and market handling. Major reasons for the losses are decay, especially in the case of fresh fruits and vegetables, insect and rodent damage, and fungal infection.

There is much to gain from reducing post-harvest losses. Interventions are appropriate at many different levels. Local processing may be one of the most promising interventions. Local agro-processing engineering not only restricts post-harvest losses, but also increases the economic value of harvested agricultural products. Although Africa produces numerous crops that are needed in industrialized countries, most processing does not take place in Africa. It is easy to appreciate that to alleviate poverty African countries must cease to be mere producers of bulk agricultural commodities. Rather, the agricultural products must first be processed into finished products for domestic consumption and for export. The latter movement of value adding along the production-market chain is now virtually absent in Africa and requires more knowledge, expertise and experience of other steps in the production-market chain. That knowledge and expertise is currently only available at a limited number of places. A policy oriented towards such development would promote much more food processing, food technology and non-food technological innovations in Africa.

Prioritization of farming systems

Farming systems in Africa are characterized by their diversity. It is not possible to identify one or two systems that predominate – the top six systems provide together 80 percent of all food production. Thus it is virtually impossible to identify one farming system with the best opportunities for improvement. In fact many systems have attractive technical opportunities but require investment, promotion and appropriate policies at micro,



meso and macro level. To prevent spreading resources too thinly, the Study Panel has developed a procedure for prioritization, taking as a starting point the question raised by the Secretary General of the United Nations: What systems could potentially contribute most to increased agricultural productivity and improved food security?

Two main indicators – agricultural added value and the numbers and prevalence of underweight children – are used to assess the potential of the various farming systems to impact on these two ultimate goals. The first indicator gauges the productivity potential of a system, whereas the second indicator reflects the extent of the malnutrition that needs to be overcome to achieve food security. Systems are considered priority systems when both the productivity potential and the extent of malnutrition are high. The higher the former, the greater the effect of productivity improvement on the generation of new income streams for smallholders and in restraining price increases, which benefit poor consumers. The greater the extent of malnutrition the more the productivity gains will benefit those most in need of improved food and nutrition security.

For 10 predominating farming systems, indices were calculated for the number of underweight pre-school children, the percentage of underweight pre-school children and the agricultural added value (Table 3.5). All measures were indexed to the highest value among the considered farming systems. Table 3.5 also shows a composite index where the percentage

Table 3.5 Indicators for priority assessment in ten major African farming systems

Farming system	Agricultural Value Added Index	No. of UCI	% of UCI	No. and % of UCI
Irrigated	100	22	33	28
Maize mixed	73	83	73	81
Tree crop based	67	35	62	50
Commercial	61	7	25	17
Sparse/arid	55	11	77	46
Forest based	34	44	81	65
Cereal/root crop based	28	100	93	100
Root crop based	14	65	77	74
Highland perennial	12	52	91	74
Agro/pastoral	9	65	100	85

Sources: Agricultural Value Added (% of GDP) –(World Bank, 2003); Underweight children (CIESIN, and the Hunger Task Force of the UN Millenium Development Goals program).

UCI = Underweight Children Index

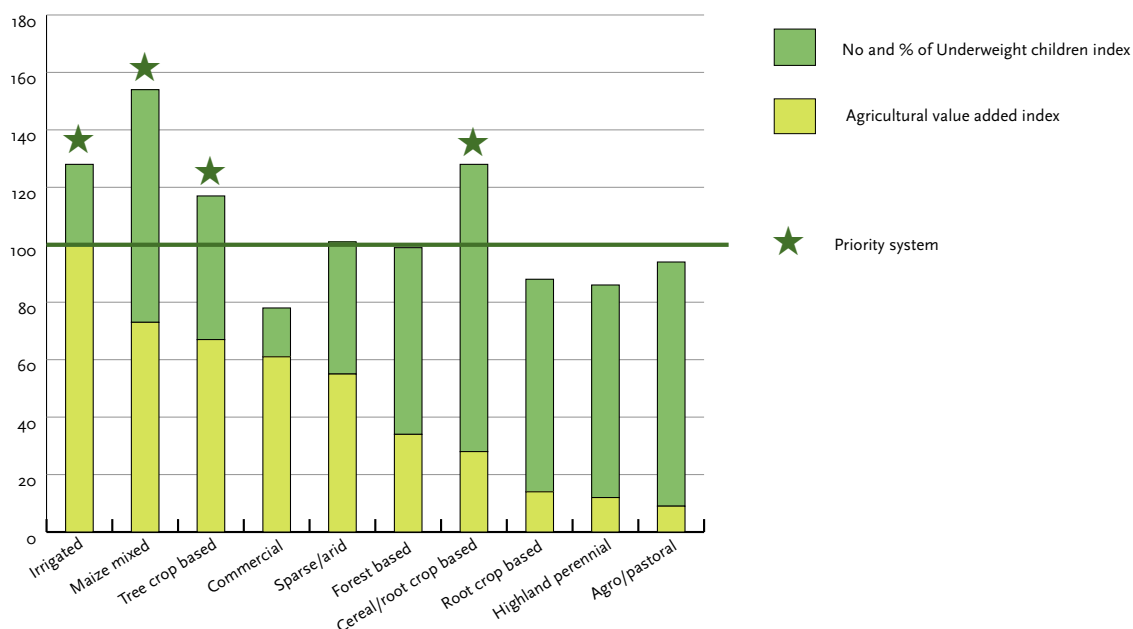


Figure 3.8 Characteristics of the priority systems (Dixon et al., 2001) and the indices as described in Table 3.5.

and number of underweight children are assigned equal weights. This composite underweight pre-school children index is plotted with the agricultural added value index in Figure 3.8.

Four farming systems are considered priority systems from the point of view of the economic value of agricultural production and the extent of malnutrition. While no system should be neglected in Africa, the Study Panel considers that the best chances of measurable food security benefits from productivity gains from a continental perspective will occur in the following systems: maize mixed, cereal/root crop mixed, irrigated and tree crop based. The choice of priority systems may be influenced by the methodology used. By using indicator countries for the various farming systems as explained earlier in this chapter, farming systems that do not cover a major part of any country are excluded from the analysis. A more refined analysis requires disaggregated data that are currently not available. These data should be generated in a follow up to this study at local, regional and national levels. The Study Panel recognizes that within specific countries and regions of Africa, system priorities may differ from the four identified by the Study Panel for the whole continent, even using

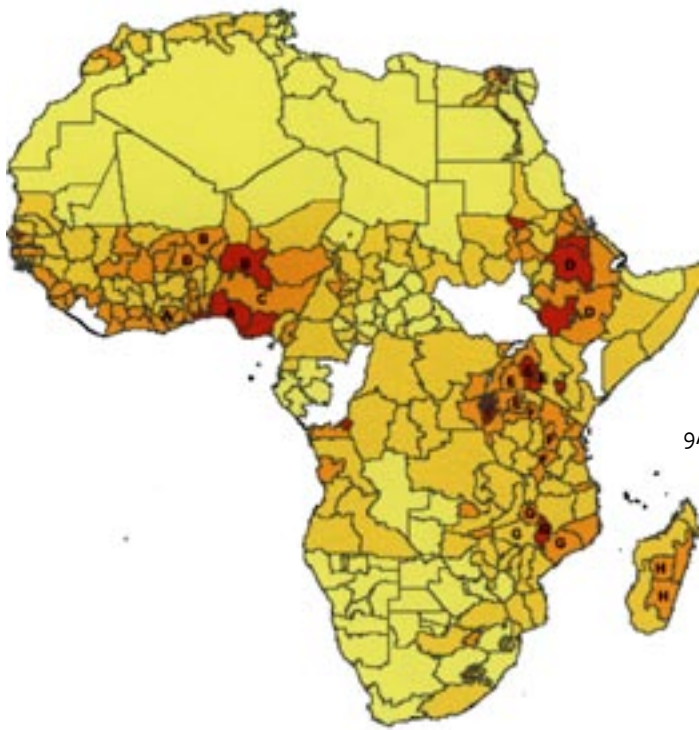
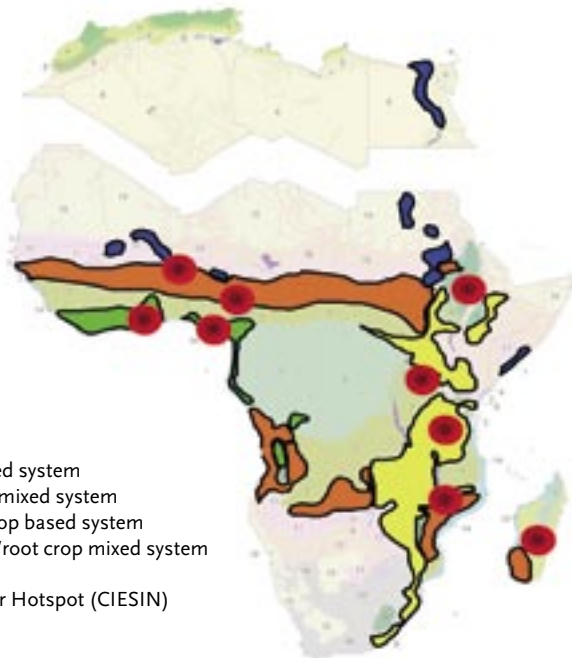
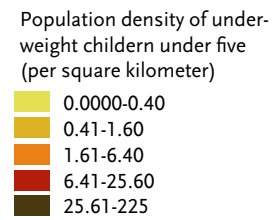
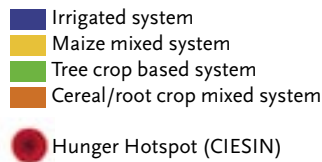


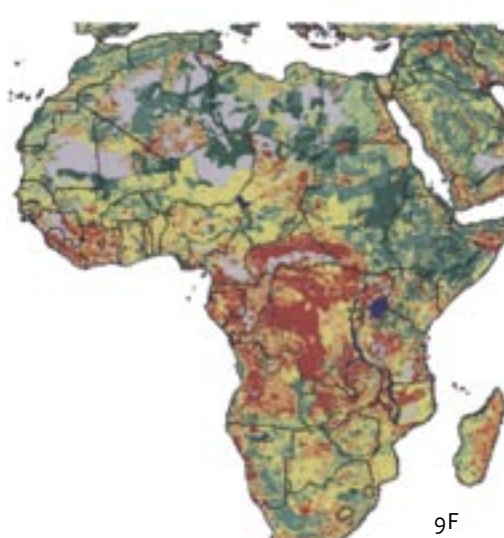
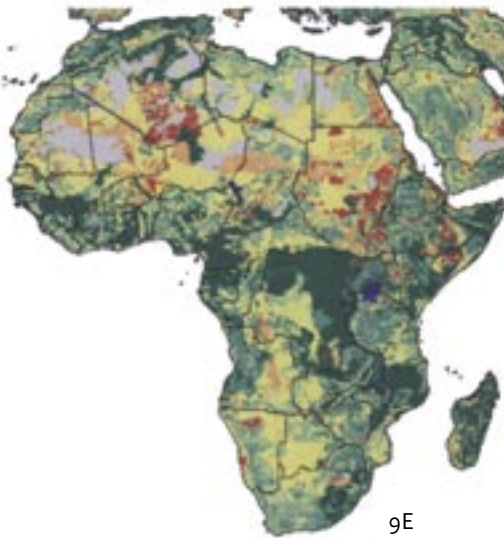
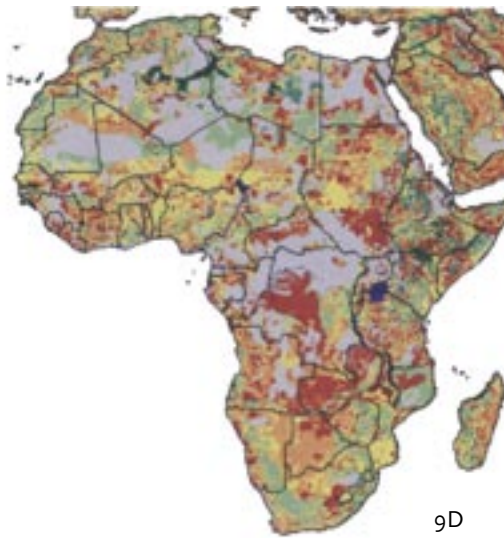
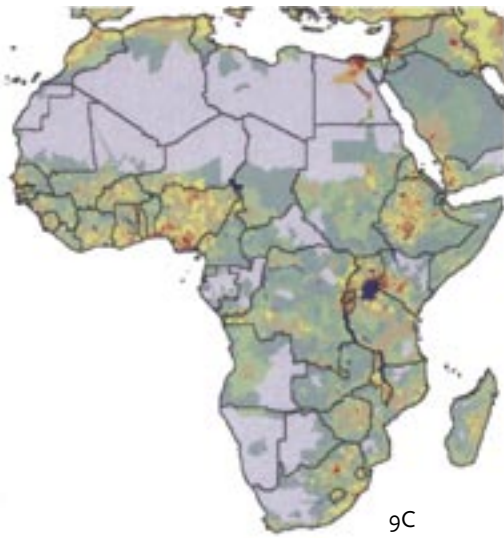
Figure 3.9 Population density of underweight children under five and proposed hunger hotspots (A), proposed hunger hotspots overlayed with farming systems (B), population density in 1995 (C), soil constraints combined (D), soil texture constraints (E) and soil fertility constraints (F). *Sources:* CIESIN and Hunger Task Force (A and B, unpublished data) and GAEZ database © 2000 Copyright IIASA and FAO, (C, D, E and F).

9A



9B





Legend 9C

- Unidentified
- <= 1 pers/km²
- 1-5 pers/km²
- 5-10 pers/km²
- 10-20 pers/km²
- 20-50 pers/km²
- 50-100 pers/km²
- 100-200 pers/km²
- 200-500 pers/km²
- 500-1000 pers/km²
- > 1000 pers/km²
- water

Legend 9D, E and F

- Unidentified
- No constraints
- 1-20: very few constraints
- 20-40: few constraints
- 40-60: partly with constraints
- 60-80: frequent severe constraints
- 80-95: very frequent severe constraints
- 100: unsuitable for agriculture
- water



the same criteria. It therefore encourages subregional organizations and national agricultural research systems (NARS) to undertake similar priority assessments to complement the Study Panel's continental analysis.

In Figure 3.8 the farming systems, as described according to the methodology, are based on their occurrence and their contribution to total food production. This description and characterization is based on the way systems operate and function at present. However, it does not indicate their full potential in the long run and how they may contribute to future food production. Systems are not static; they change continuously, due to the influence of exogenous factors and due to endogenous processes such as improved access to inputs, technological improvements, and better knowledge and insight. In Chapter 4 the possibilities of technological innovations are described. Such innovations will help to minimize the effect of growth- and yield-reducing factors and eliminate growth- and yield-limiting factors.

Figure 3.9A presents the underweight children densities and proposed hunger hotspots as assessed by the Centre for International Earth Science Information Network (CIESIN) for the Hunger Task Force of the UN Millennium Development Goals program. They defined child underweight density as the number of underweight pre-school children under five years of age per square kilometre on a subregional basis and used these data as indicator for hunger hotspots. These hotspots were overlaid with Dixon's farming systems to indicate which farming systems are prevalent in the occurrence of hunger (Figure 3.9B). Not surprisingly, the hotspots coincide with the regions with the highest population density (Figure 3.9C). In general, these regions are characterized by relatively few inherent constraints for agriculture. According to the GAEZ (2003), these constraints are based on three components: soil constraints, climate constraints and slope constraints. When combined, these constraints reveal areas that are relatively suitable for agriculture. Figures 3.9D-F show more detailed information about soil constraints. Overall, the soil physical characteristics like depth and drainage are favourable over the entire continent and do not represent constraints. In contrast, both soil texture (Figure 3.9E) and soil fertility (Figure 3.9F) vary substantially over the continent. A combination of both constraints reveal regions with unfavourable soil conditions (Figure 3.9D) and as expected these regions are not densely populated (Figure 3.9C). Mainly due to climate constraints, not all regions with favourable soil conditions have developed human settlements. Yet in line with global patterns, relatively fertile regions were attractive and therefore now are



also the most densely populated regions. Although inherently fertile, the actual situation is often that these soils are severely depleted of nitrogen and phosphorus and/or severely eroded. Replenishment is needed to restore inherent fertility.

Overlaying the data of Figure 3.9 with the prioritized farming systems as presented in Figure 3.8 confirms that three of the farming systems are major according to both classifications. These farming systems are the maize-mixed, the tree-crop based and the cereal/root crop based. These systems combine the occurrence of serious hunger with a relatively high agricultural productivity potential. These systems are also among the five that Dixon and colleagues selected on the basis of their potentials for poverty reduction and agricultural growth, as well as their importance in demographic terms (Dixon et al., 2001). Like the Study Panel, Dixon and colleagues also include the irrigated system, suggesting that the greatest overall agricultural growth potential in the immediate future is found in the irrigated, maize mixed, cereal/root crop and tree crop systems (Figure 3.8).

Comparing the hunger hotspots map (Figure 3.9B) with the soil constraint map (Figure 3.9D) shows that, besides the prioritized systems also the highland temperate mixed farming system combines serious hunger with high agricultural potential. Different criteria thus may yield different priorities and care must be taken not to rely too heavily on a single prioritization system.

Table 3.6 presents further data characterizing the suggested four continental priority systems in which almost 60 percent of the number of underweight children in Sub-Saharan Africa is located. Table 3.7 shows annual productivity growth for the major commodities over the last two decades (1980-2000) and the two preceding decades (1960-1980).

The maize mixed system has had lower trends in productivity since 1981 than prior to that for five of the eight crops that dominate it. In the irrigated and tree crop systems on the other hand, productivity trends for all crops were higher since 1981 than before. These systems involve more commercial crops than in the other two priority systems. In all, except one case in the cereal/root crop based system, this was also true. It is notable that for both the food and the non-food crops in 75 percent of cases the productivity trends were higher since 1981 than prior to that so there does not seem to have been a difference in performance over time in this respect. It does seem however that productivity growth in general has been higher with food crops in the priority systems.



Table 3.6 Major characteristics of suggested priority farming systems

	Maize mixed	Irrigated	Cereal/root crop based	Tree crop based
A. Major characteristics*				
Total population	95,000,000	14,000,000	85,000,000	50,000,000
Agricultural population	60,000,000 (15)	7,000,000 (2)	59,000,000 (15)	25,000,000 (7)
Total area in ha	246,000,000 (10)	35,000,000 (1.4)	312,000,000 (13)	73,000,000 (3)
Cultivated area in ha	32,000,000 (19)	3,000,000	31,000,000 (18)	10,000,000 (6)
Irrigated area in ha	400,000	2,000,000	400,000	100,000
Agroecological zone	Dry subhumid to moist subhumid	Various	Dry subhumid	Humid
Vulnerability	Drought and market volatility	High costs	Drought	Price fluctuations
Prevalence of poverty	Moderate	Limited	High	Limited-moderate
Agriculture growth potential	Good	High	Limited	Moderately high
B. indices				
Malnutrition index	81	28	100	50
Agricultural added value index	73	100	28	67
C. Dominant (++) and other important (+) commodities				
Maize	++	++	++	+
Rice	+	++		+
Sorghum	+	+	++	+
Millet	+		++	+
Wheat		++		
Cassava	++		++	++
Yam			++	++
Cocoyam				++
Pulses	+		+	
Vegetables/Melon		++		
Banana/Plantain	+			
Cotton	+		+	
Coffee	+			+
Oil Palm				+
Cocoa				+
Rubber				+
Tobacco	+			
Groundnuts	+			
Sunflower	+			
Cattle population	36,000,000	3,000,000	42,000,000	2,000,000
Poultry	+	+		
Goats	+		+	+

Sources: A. Dixon et al. (2001). Regions are North Africa and the Middle East for the irrigated system and Sub-Sahara Africa for the other farming systems. B. Data as presented in Table 3.5. C. Dixon et al. (2001) and FAO (2003).

* Values are absolute (and percentages)



Table 3.7 Productivity trends for various commodities in the suggested priority farming systems

Crop	Decades	Annual % yield increase over two periods of two decades			
		Maize mixed	Irrigated	Cereal/root crop based	Tree crop based
Maize	1961-1980	2.63	1.97	-0.36	0.27
	1981-2002	-0.04	3.30	3.83	2.56
Rice	1961-1980	0.98	0.2	-0.94	1.28
	1981-2002	0.69	2.71	1.35	2.98
Sorghum	1961-1980	0.16	0.32	0.72	0.58
	1981-2002	0.64	2.00	1.68	2.28
Millet	1961-1980	1.22		0.04	-1.07
	1981-2002	0.54		1.92	0.11
Wheat	1961-1980	6.92	1.92		
	1981-2002	-0.08	3.19		
Cassava	1961-1980	2.80		1.37	-0.06
	1981-2002	0.03		2.09	1.75
Yam	1961-1980			1.29	
	1981-2002			0.92	
Pulses	1961-1980			0.90	
	1981-2002			4.48	
Vegetables/Melon	1961-1980		0.21		
	1981-2002		1.13		
Banana	1961-1980	-0.4			
	1981-2002	1.4			
Cotton	1961-1980	2.69			
	1981-2002	0.77			
Coffee	1961-1980				-0.34
	1981-2002				0.86
Oil Palm	1961-1980				0.44
	1981-2002				0.48
Cocoa	1961-1980				-0.15
	1981-2002				1.94

Source: FAO (2003). Indicator countries: Maize mixed (Malawi and Zimbabwe, 70%; and Tanzania, Uganda and Zambia, 50%); Irrigated (Egypt); Cereal/root crop mixed (Gambia, Guinea-Bissau and Mozambique, 70%; and Benin and Burkina Faso, 50%) and tree crop based (Guinea and Liberia, 70%; and Ghana, 50%). The percentages refer to minimum proportions of the countries that are covered by the indicated systems.



Conclusions

The many African farming systems described highlight the fact that in addressing the diverse problems of African productivity and food security, regionally mediated rather than continent-wide strategies will be needed. Since the top six systems cover 80 percent of Africa's food production, it is extremely difficult to identify one system with the best opportunity to generate impact.

In identifying systems that could potentially contribute most to increased agricultural productivity and improved food security, the Study Panel has undertaken a priority assessment of 10 major African farming systems. Two main indicators were used – an agricultural value added index and a composite underweight pre-school children index. By plotting the summation of the two indices for all 10 farming systems, four emerged as 'best bets' for productivity gains that would have the potential to deliver most benefits for the most malnourished.

More detailed analyses of the potential of these four systems is discussed in Chapter 4. The technology options likely to result in the best technical and best ecological outcomes will be described and their functioning illustrated. Increases in land productivity can in many cases be combined with increases in the productivity of labour and other factors. The latter are needed, as labour constraints are already limiting the number of cultivated hectares in many systems and input markets are underdeveloped. Labour constraints will continue to worsen because the young rural labour force in many African countries is thinning due to HIV/AIDS and other diseases, reinforced by poor nutrition combined with the magnetic power of urbanized areas.



References

- Ahlawat, I. P. S., and D. S. Rana. 1998. Agro-techniques. In: Yadav, R.L., P. Singh, R. Prasad, and I.P.S. Ahlawat. Fifty years of agronomic research in India. New Delhi: Indian Society of Agronomy.
- Ahmed, M. M., and J. H. Sanders. 1998. Shifting from extensive to intensive agricultural systems: A case study in the Sudan. *Agricultural Systems*, 58: 253-268.
- Ahmed, M. M., J.H. Sanders, and W. T. Nell. 2000. New sorghum and millet cultivar introduction in Sub-Saharan Africa: Impacts and research agenda. *Agricultural Systems*, 64: 55-65.
- Amleson, S. 2004. Eritrea country paper. In: Omare, A., and D. Sheikh. (Eds.) Study on science and technology strategies for improving agricultural productivity and food security in Africa – Abstracts of presentations and synthesis of discussions. Proceedings of the Workshop for Eastern and Central Africa, Nairobi, Kenya: ASARECA / IAC. Accessible at < www.interacademycouncil.net >
- Bouma, J., A. Kuyvenhoven, B. A. M. Bouman, J. C. Luyten, and H. G. Zandstra. (Eds.) 1994. Eco-regional approaches for sustainable land use and food production. International Potato Centre. Dordrecht, Boston, London: Kluwer Academic Publishers.
- Breman, H., J. J. R. Groot, and H. van Keulen. 2001. Resource limitations in Sahelian Agriculture. *Global Environmental Change*, 11: 59-68.
- Casenave, A., and C. Valentin. 1992. A 1989. Les états de surface de la zone sahélienne. Influence sur l'infiltration. Edition de l'ORSTOM. Institut Français de Recherche Scientifique pour le Développement en Coopération. Paris.
- De Jager, A., D. Onduru., M. S. van Wijk, J. Vlaming, and G. N. Gachini. 2001. Assessing sustainability of low-external-input farm management systems with the nutrient monitoring approach: A case study in Kenya. *Agricultural Systems*, 69: 99-118.
- Delgado, C., M. W. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 1999. Livestock to 2020: The next food evolution. Food, agriculture and environment discussion paper 28. International Food Policy Research Institute, Food and Agriculture Organization, and International Livestock Research Institute
- DeVries, J., and G. Toenniessen. 2002. Securing the harvest: Biotechnology, breeding and seed systems for African crops. New York: The Rockefeller Foundation.
- De Wit, C. T. 1992. Resource use efficiency in agriculture. *Agricultural Systems*, 40: 125-151.
- Dixon, J., A. Gulliver, and D. Gibbon. 2001. Farming systems and poverty: Improving farmers livelihoods in a changing world. Food and Agriculture Organization, Rome, and World Bank, Washington, DC
- Evenson, R. E., and D. Gollin. 2001. The green revolution at the end of the twentieth century. Paper prepared for IAC's standing panel on impact assessment. Technical Advisory Committee (TAC) Secretariat, Food and Agriculture Organization, Rome.
- Fan, S., P. Hazell, and T. Haque. 2000. Targeting public investments by agroecological zone to achieve growth and poverty alleviation goals in rural India. *Food Policy*, 25(4): 411-428.
- Fan, S., P. Hazell, and S. Thorat. 2000. Government spending, growth and poverty in rural India. *American Journal of Agricultural Economics*, 82(4): 1038-1051.
- Fan, S., L. Zhang, and X. Zhang. 2002. Growth, inequality, and poverty in rural China: The role of public investments. IFPRI research report 125. International Food Policy Research Institute. Washington, DC.
- FAO (Food and Agriculture Organization). 1989. Prevention of post-harvest food losses: Fruits, vegetables and root crops. A training manual. Rome, Italy.
- FAO. 1997. Food production: The critical role of water. Technical background document no. 7. World Food Summit, 13-17 November 1996. Rome, Italy.



- FAO. 1999. Expert consultation on bridging the rice yield gap in the Asia-Pacific region. 5-7 October 1999. Bangkok, Thailand. <www.fao.org/ag/AGP/AGPC/doc/field/commerce/session/54.htm#yie>
- FAO. 2003. FAOSTAT database.
- French, R. J., and J. E. Schultz. 1984. Water use efficiency of wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate. *Australian Journal of Agricultural Research*, 35: 743-764.
- GAEZ (Global Agro-Ecological Zones). 2003. GAEZ database. <www.fao.org/WAICENT/FAOINFO/AGRICULT/AGL/agll/gaez/index.htm>
- IITA (International Institute of Tropical Agriculture). 2003. Crops and farming systems. <www.iita.org>
- ILRI (International Livestock Research Institute). 2000. Livestock strategy to 2010: Making the livestock revolution work for the poor. Nairobi Kenya.
- IPCC (Intergovernmental Panel on Climate Change). 2001. Incidence and evolution of climate in the regions: Evaluation of vulnerability – Africa. Special Report. United Nations Environment Program (UNEP) and World Meteorological Organization (WMO). Geneva.
- ISNAR (International Service for National Agricultural Research). 2004. Method in our madness: Making sense of ecoregional research with modelling tools and processes. The Hague, Netherlands.
- Ittersum, M. K. van, and R. Rabbinge. 1997. Concepts in production ecology for analysis and quantification of agricultural input-output combinations. *Field Crop Research*, 52: 197-208.
- Ittersum, M. K. van, R. Rabbinge, and H. C. van Latesteijn. 1998. Exploratory land use studies and their role in strategic policy making, *Agricultural Systems*, Volume 58, Issue 3: 309-330.
- Koranteng, K.A. 2003. Risks to coastal fisheries in Sub-Saharan Africa. Paper presented to Coastal Zones in Sub-Saharan Africa: A scientific review of the priority issues influencing sustainability and vulnerability in coastal communities. Conference held at the Natural History Museum & Royal Society, London 27/28 May 2003.
- Lamachère J.M., and G. Serpanié. 1991. Valorisation agricole des eaux de ruissellement et lutte contre l'érosion sur champs cultivés en mil en zone soudano-sahélienne, Bidi, Burkina Faso. In: Kergreis A., and J. Claude. Eds. Utilisation rationnelle de l'eau des petits bassins versants en zone aride. Paris: John Libbey Eurotext.
- Li, X.Y., J. D. Gong, Q. Z. Gao, and F.R. Li. 2001. Incorporation of ridge and furrow method of rainfall harvesting with mulching for crop production under semiarid conditions. *Agricultural Water Management*, 50: 173-183.
- Lhoste, P and D. Richard. 1993. Contribution de l'élevage à la gestion de la fertilité à l'échelle du terroir. *Reseau Erosion Bulletin* no 14. p. 463-489
- Oldeman, L.R. 1999. Soil degradation: a threat to food security? In: Bindraban, P. S., H. van Keulen, A. Kuyvenhoven, R. Rabbinge, and P. W. J. Uithol. Eds. Food security at different scales: Demographic, biophysical and socio-economic considerations. *Quantitative Approaches in Systems Analysis*, No. 21, Wageningen, 105-117.
- Penning de Vries, F., P. Teng, K. Metselaar. Eds. 1993. Systems approaches for agricultural development. International Rice Research Institute. Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Perry, B. D., T. F. Randolph, J. J. McDermott, K. R. Sones, and P. K. Thornton. 2002. Investing in animal health research to alleviate poverty. International Livestock Research Institute. Nairobi, Kenya.
- Pieri, C. 1989. Fertilités des terres de savanes. Ministère de la coopération et CIRAD-IRAT. Paris.



- Rabbinge, R. 1995. Ecoregional approaches, why, what and how. In: Bouma, J., A. Kuybenhoven, B. A. M. Bouman, J. C. Luyten, and H. G. Zandstra. Eds. Ecoregional approaches for sustainable land-use and food production. Dordrecht, The Netherlands: Kluwer Academic Publisher.
- Rockström, J. 2001. Green water security for the food makers of tomorrow: windows of opportunity in drought-prone savannahs. *Water Science and Technology*, 43: 71-78.
- Rosegrant, M. W., M. S. Paisner, S. Meijer, and J. Witcover. 2001. Global food projections to 2020: Emerging trends and alternative futures. International Food Policy Research Institute. Washington DC.
- Rosegrant, M. W., X. Cai, S. Cline, and N. Nakagawa. 2002. The role of rainfed agriculture in the future of global food production. Environment and production technology division discussion paper no. 90. International Food Policy Research Institute. Washington, DC.
- Ryan, J. G., and D. C. Spencer. 2001. Future challenges and opportunities for agricultural R&D in the semi-arid tropics. International Crops Research Institute for the Semi Arid Tropics. Patancheru, Andhra Pradesh, India.
- Sanchez, P. E. 2002. Soil fertility and hunger in Africa. *Science*, 295, 2019-2020.
- Scherr, S. J., and S. Yadev. 2001. Land degradation in the developing world: Issues and policy options for 2020. In: Pinstrup-Andersen, P., and R. J. Lorch. Eds. The unfinished agenda: Perspectives on overcoming hunger, poverty, and environmental degradation. International Food Policy Research Institute. Washington, DC.
- Shank, R. 2003. STRIGA: Facts and peculiarities (information report). United Nations Development Programme. <www.sas.upenn.edu/African_Studies/eue_web/striga.htm>
- Smaling, E. M. A., S.M. Nandwa, H. Prestele, R. Roetter, and F. N. Muchena. 1992. Yield response of maize to fertilizers and manure under different agro-ecological conditions in Kenya. *Agriculture, Ecosystems, and Environment*, 41: 241-252.
- Smith, J., A. D. Barau, A. Goldman, and J. H. Mareck. 1994. The role of technology in agricultural intensification: The evolution of maize production in the Northern Guinea Savanna of Nigeria. *Economic Development and Cultural Change*, 42(3): 537-554.
- Swaminathan, M. S. 1999. I predict: A century of hope. Towards an era of harmony with nature and freedom from hunger. Madras, India: East West Books.
- ten Berge, H. F. M., T.M. Thiyagarajan, Q. Shi, M.C.S. Wopereis, H. Drenth, and M. J. W. Jansen. 1997. Numerical optimization of nitrogen application to rice. Part I: Description of MANAGE-N. *Field Crops Research*, 51: 29-42.
- Teng, P. S., M. J. Kropff, H. F. M. ten Berge, J. B. Dent, F. P. Lansingan, and H. H. van Laar. Eds. 1997. Applications of systems approaches at the farm and regional level. Vol. 1. International Rice Research Institute. Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Thornton, P. K., R.L. Kruska, N. Henninger, P. M. Kristjanson, R. S. Reid, F. Atieno, A. N. Odero, and T. Ndegwa. 2002. Mapping poverty and livestock in the developing world. International Livestock Research Institute. Nairobi, Kenya.
- UNEP (United Nations Environment Program). 1997. World atlas of desertification. Second edition. United Nations Environment Program. Nairobi, Kenya.
- Wilson, S. E. 2001. Global warming changes the forecast for agriculture. In: Pinstrup-Andersen, P., and R. J. Lorch. Eds. The unfinished agenda: Perspectives on overcoming hunger, poverty, and environmental degradation. International Food Policy Research Institute. Washington, DC.
- World Bank. 2003. World development indicators. Washington, DC <www.worldbank.org/data/dataquery.html>



WRR (Netherlands Scientific Council for Government Policy). 1995. Sustained risk: A lasting phenomenon. Reports to the government 44. The Hague, The Netherlands.

Zhu, Y. Y., H. R. Chen, Y. Y. Wang, Z. S. Li, Y. Li, J. H. Fan, J. B. Chen, J. X. Fan, S. S. Yang, G. L. Ma, L. P. Hu, J. Y. Zou, and L. Hei. 2001. Diversifying variety for the control of rice blast in China. *Biodiversity*, 2001, 2: 1, 10-14; 9 ref.



4. Science and technology options that can make a difference

Correct and diligent application of a range of technology options can lift crop and animal production and make more effective, efficient use of land, labour and capital. This chapter explores the technologies available and their potential to increase productivity of land, labour and inputs, and will illustrate the role of science to adapt, develop and introduce such technologies. In the second section, the four high-priority farming systems, selected in Chapter 3 are evaluated on their changes in land, labour and input productivity over the past four decades.

Yield gap analysis according to the production ecological principles cannot be fully presented for the farming systems due to the lack of a comprehensive analysis and adequate data. Therefore the yield gaps are presented in the third section for several commodities in those systems, based on field data. These yield gaps provide some insight in the constraints and opportunities for productivity increase. In the fourth section various technologies have been described in generic terms, but with special emphasis to African situations.

The fifth section describes the complexity of the diversified farming systems in Africa. While much descriptive information is available about these systems, there is no systematic insight to recommend blueprint measures to enhance their productivity. This information does reveal encouraging results, but much systematic research for a complete picture is still needed. The effective application of new technologies can only take place with appropriate institutional arrangements in place and enabling environments created. The chapter concludes with suggestions about how such conditions can be fulfilled.

Production developments and constraints in priority systems

Chapter 3 highlighted the four farming systems (maize mixed, cereal/root crop, irrigated and tree crop based) with greatest potential to increase agricultural productivity and improve food security. A farming system must be studied in its entirety to assess productivity of its complex, wide-ranging mixture of crops, but this is difficult when productivity data are commodity based for specific crops. To be more specific about performances within



farming systems, production data are used to assess yield gaps and to identify constraining factors and opportunities for improvements.

The national net production index number of the Food and Agriculture Organization (FAO) is chosen to illustrate changes over the past four decades in the total commodity production from farming systems. The indices are calculated by the Laspeyres formula (FAO, 2003), which aggregates different commodities (production minus feed minus seed) valued at constant 1989-1991 prices. This means that the production index number represents a relative value of net production volumes. For the purpose of the current study, the production index number is indexed for the base period 1960 (100). Production index data are compared with labour input, agricultural land use and fertilizer use, where possible separately for crop and livestock production. The data of indicator countries are aggregated to farming systems data using the same calculation method as in Chapter 3.¹ Changes in production index number are compared with changes in the relative use of agriculture area, labour input and fertilizer consumption in Figures 4.1, 4.2 and 4.3. The first three variables are expressed as indices and set to 100 in 1960. Fertilizer consumption could not be indexed. Small absolute changes in the generally low fertilizer use – often a few kilograms per hectare only – result in huge relative changes. Therefore the absolute use of fertilizers is presented in the graphs on a second Y-axis. This presentation also reveals the large variation in fertilizer consumption among countries. Although the fertilizer data refer to total use over all agricultural activities, fertilizers are probably mainly used for crop production and not for fertilizing pastures. Therefore fertilizer data are only presented in the figures of crop production (Figure 4.2).

The analyses reveal large differences among farming systems. In all four systems, land productivity rose consistently over the 40-year period, when crop and livestock production were both considered (Figure 4.1). It rose about three-fold in the irrigated system, which was far in excess of the other three systems. On the other hand, agricultural labour productivity only

¹ *Aggregation method.* The following Indicator countries comprising greater than 50%, or greater than 70% of a given farming system were identified: Irrigated, Egypt (>70%); Cereal/Root crop mixed, Gambia (>70%), Guinea-Bissau (>70%), Mozambique (>70%), Benin (>50%) and Burkina Faso (>50%); Maize mixed, Malawi (>70%), Zimbabwe (>70%), Tanzania (>50%), Uganda (>50%) and Zambia (>50%); and Tree crop based, Guinea (>70%), Liberia (>70%) and Ghana (>50%). The country data are weighed for the percentage occupied by the given farming system (>50% or >70%) and the agricultural land area to provide a value for that farming system.



rose in the irrigated system, being virtually stagnant in the other three systems.

In all four systems, crop land use rose substantially, reflecting the fact that (as shown in Chapter 2) land expansion explained about 60 percent of the increase in cereal production in all of Africa. Only 40 percent was due to increased cropland productivity. In these four systems it seems that the contribution of cropland productivity gains to total crop production may have been greater than in other systems in Africa, especially after 1985 (Figure 4.2). Again the irrigated system recorded by far the highest land productivity growth. It was two to three times greater than in the other three systems. It appears that crop fertilizer use per hectare rose in all four systems during the period, and its rate of growth was greater than the rate of growth in the area of crop land, especially in the irrigated system. Another factor that is not captured in Figure 4.2 is the increase in the intensity of land use over the period. Especially in irrigated and higher rainfall systems, there has been a trend towards growing two and sometimes three crops a year from the same land. The measure of land area used here does not reflect these changes. Hence the apparent land productivity increases are in fact overestimates of the increases in productivity per unit of total or gross cropped land. They in fact only represent the productivity per unit of net cropped land.

In the maize mixed system, fertilizer use was a mere 3 kilograms per hectare in 2000, declining from 3.5 kilograms per hectare in the 1980s and 1990s. Average rates reach are the highest at 12 and 8 kilograms per hectare in Malawi and Zimbabwe, respectively. These may be atypical of the maize mixed system in Africa because of the highly subsidized starter pack programs in Malawi and the importance of the large commercial farm activities in Zimbabwe. Application rates are insignificant in the other countries practicing this farming system. In the irrigated system, the crop productivity increase is associated with a similar increase in fertilizer consumption, which reached absolute rates of almost 400 kilogram per hectare. This suggests that no improvement in fertilizer use efficiency was achieved over the past four decades. In the tree crop and cereal/root crop mixed systems, less than 1 kilogram per hectare of fertilizers are applied. Hence in all the rainfed mixed priority systems, there would appear to be considerable scope for increased use of fertilizers.

There has been a steady and dramatic rise in livestock productivity per hectare in all four priority farming systems (Figure 4.3). The area of permanent pastures in countries where these systems predominate has virtually remained constant over the last four decades. The question arises as to



what other inputs have contributed to the substantial increase in livestock production. Improved pastures have not increased significantly in Africa over this period. It would appear that increased use of feedgrains, improved animal disease controls and some genetic improvement may have contributed. However, this remains a topic for further research.

The analysis at the priority farming systems scale shows that area expansion has only explained part of the increase in crop production. It is likely that increased fertilizer and land use intensity and increased labour inputs

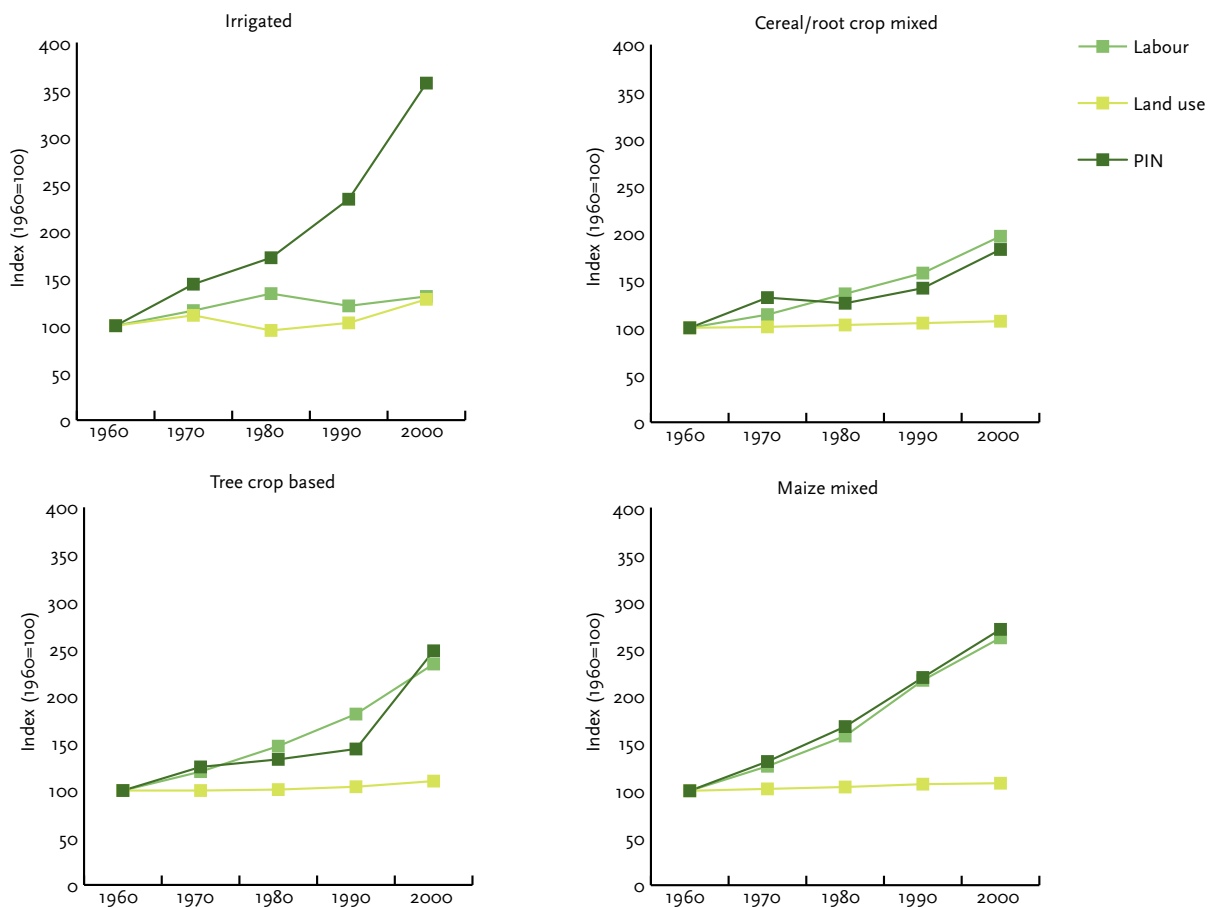


Figure 4.1 Changes in the total agricultural (crop plus livestock) production index number (PIN), agricultural land use (arable land, permanent crops and permanent pasture) and labour input in the four priority systems. *Source:* FAO (2003).



has accounted for a significant part of the crop production increase. In this process labour productivity has probably not increased at all. In contrast, agricultural labour productivity increased six-fold in Western Europe and four-fold in Northern America over the past four decades. Yields in Europe were comparable to current yield levels in Africa in the early 20th century. Labour productivity over the past century has increased two-hundred-fold in Europe.

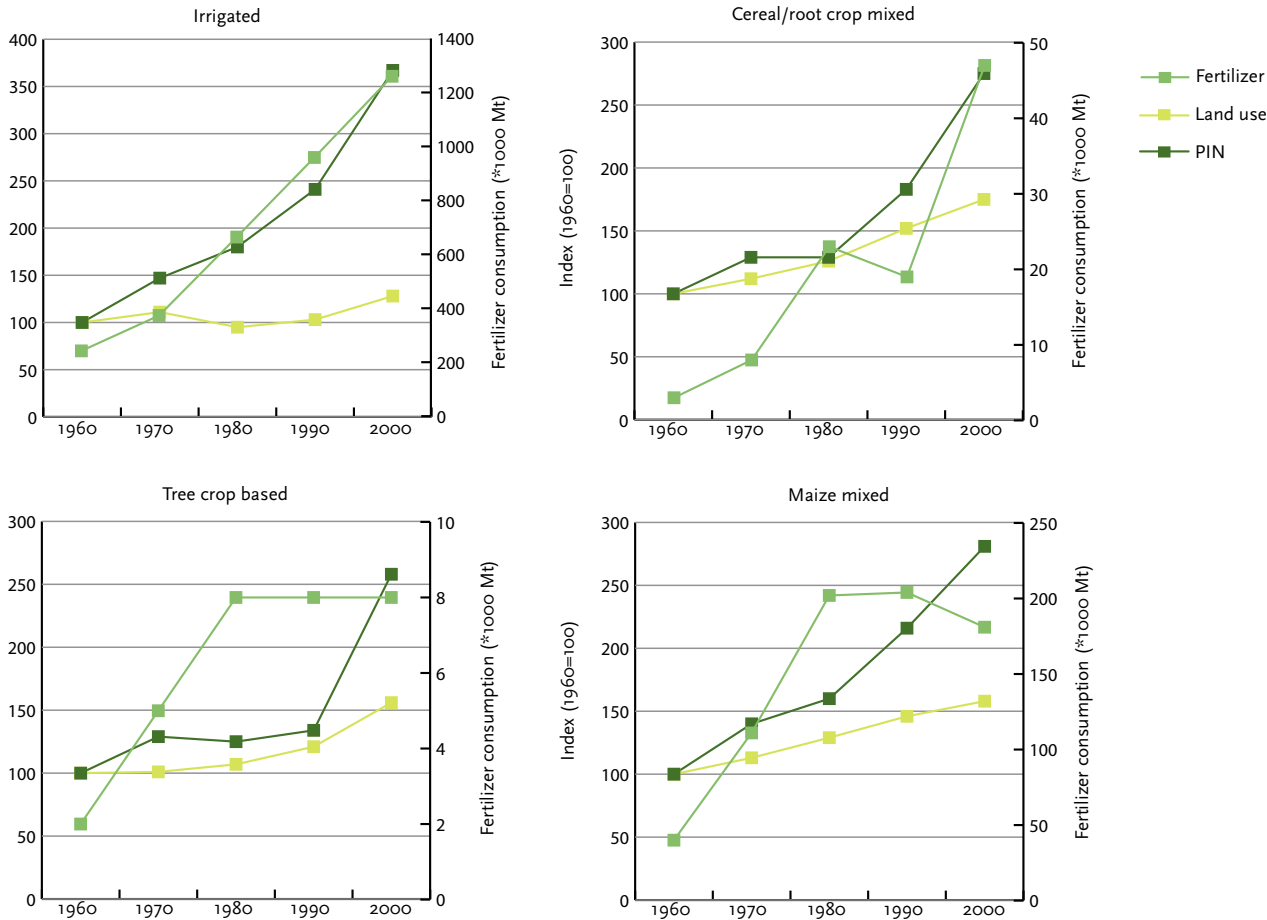


Figure 4.2 Changes in the crop production index number (PIN), crop land use (arable land and permanent crops) and fertilizer use in the four priority systems. Source: FAO (2003).

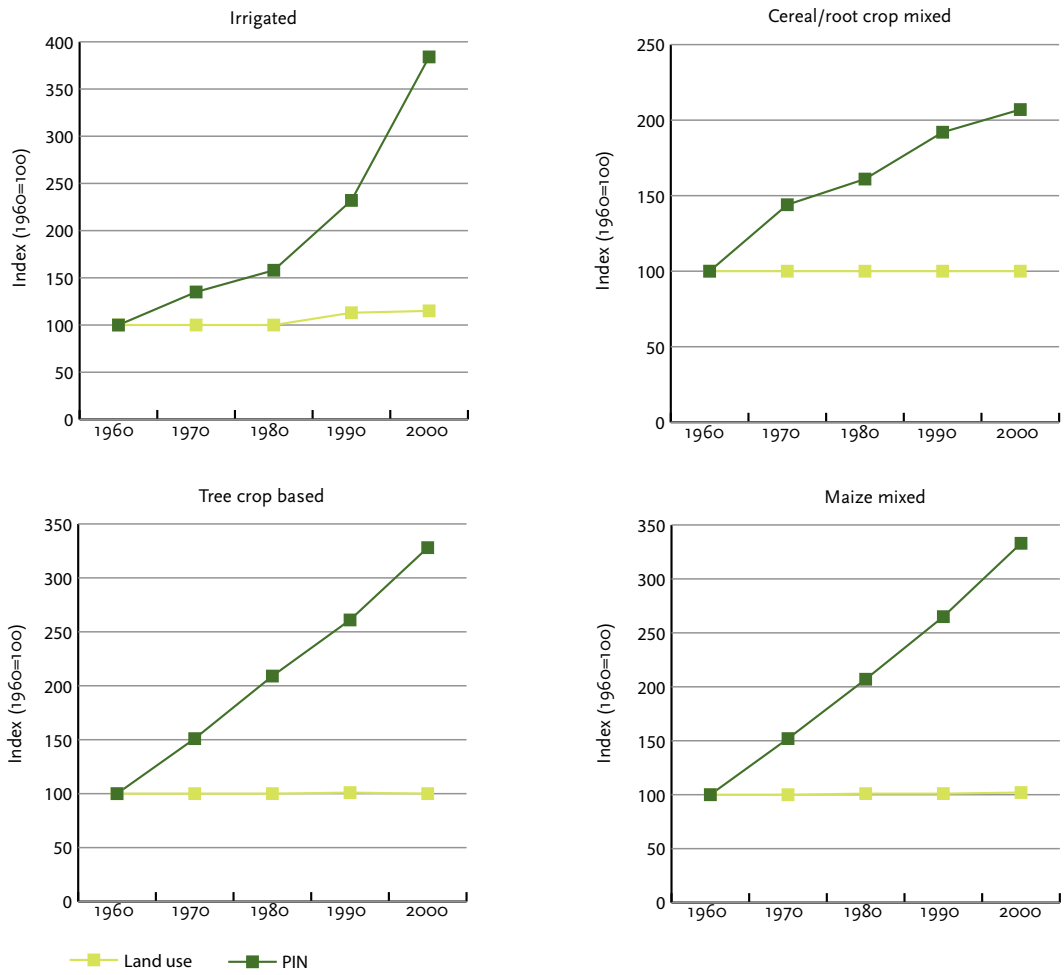


Figure 4.3 Changes in the livestock production index number (PIN) and non-crop land use (permanent pasture) in the four priority systems. *Source:* FAO (2003).



Yield gaps and constraining factors

In the previous section, the trends in development of the farming systems in terms of land, labour and fertilizer productivity were analyzed. Specific analysis of productivity in systems is virtually impossible, but yield gap analyses can be presented on a commodity basis. A generic analysis of yield gaps using production ecological principles in terms of grain equivalents is presented for the countries south of the Sahara in Box 4.1. Unfortunately no commodity-specific analyses using this concept are available for Africa. Therefore, other measures of yield gaps are used for various commodities based on readily available information from field and farm experiences, as yield gaps can also be expressed using best farmer practice or best experimental practice (See Box 3.3, Chapter 3).

Box 4.1 Production potential of Sub-Sahara Africa

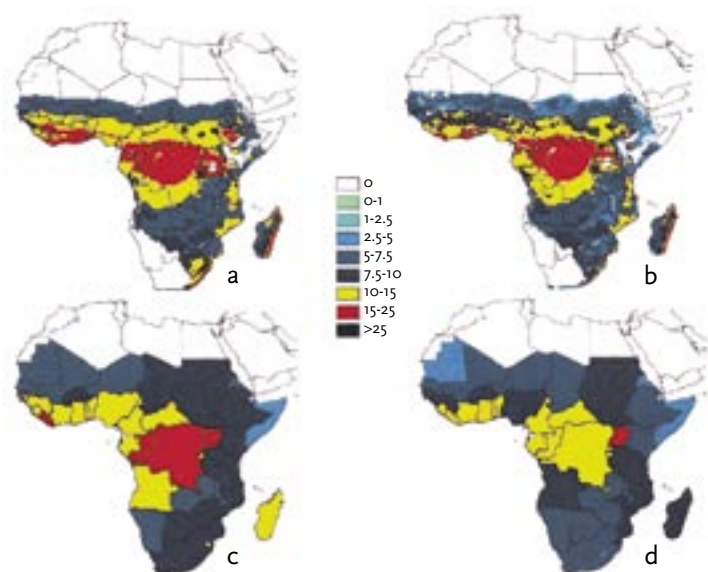


Figure 4.4 Calculated potential (a) and water-limited (b) yields (tonnes per hectare). The upper maps represent the estimations per grid cell of 5x5 minutes. The maps below are the weighted averages per country for agricultural land area (a' and b').

Source: Bindraban et al. (1999, 2000).

To create an overall view of the yield gap for Sub-Saharan Africa, Bindraban and colleagues (1999, 2000) calculated the production levels of a 'generic' cereal crop as a proxy for a wide range of crops that could be grown, with yields expressed in grain equivalents. The yield gaps obtained are therefore indicative of yields that can be obtained under the different production constraints (see Chapter 3).

The large yield gaps identified can be closed by management practices that ensure adequate inputs. These yield gaps are based on a technical analysis of the limitations of various inputs as described in Chapter 3. This approach differs from yield gap analysis generally seen in the literature which discusses gaps between farmers' fields and experimental fields. That issue is not discussed here. This yield gap analysis could be expanded with the assessment of inputs required to realize the yield increases. Further, the economic returns on these input investments could be estimated to assess the viability of such measures. The economic return on investment is, however, strongly influenced by social, institutional and marketing conditions, such as input-output prices and subsidies. Hence, the analysis reveals the feasible potentials in ecological terms. The favourable conditions for investments should be created through improved competitive markets and policies to stimulate exploitation of those potentials.

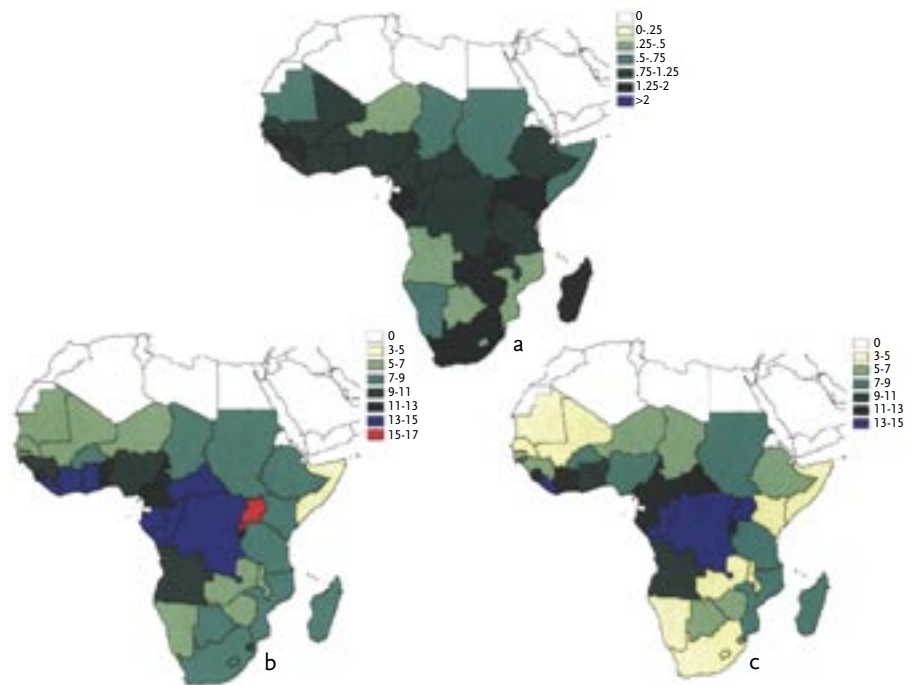


Figure 4.5 Actual average cereal yields at the national level are presented in map a. The difference between these yields with the potential yield are presented in map b, while map c presents the difference with the water-limited yield (tonnes per hectare). *Source:* Bindraban et al. (1999).

On average, yields, expressed in grain equivalents, could increase by 3-5 tonnes per hectare in semi-arid regions growing one crop per year, and by 13-17 tonnes per hectare in humid regions with two to three crops annually. If best technical means are used to eliminate the yield-limiting factors, these yields could be obtained. Detailed analyses show that water in the semi-arid Sahel region is not the main limiting factor (de Wit, 1992; Bindraban et al., 1999). Poor soil fertility (nitrogen and phosphorus shortfalls at crucial times in the growing season) limits growth rate and yield. Field experiments have confirmed this (Breman et al., 2001). The potential yields for many crops are at least 5-10 times the actual yields.

McMillan and Masters (2003) use a different approach to illustrate similar possibilities for increasing yields by comparing actual yield of cereals in Sub-Saharan Africa to yields obtained in other regions. Actual cereal yields in Asia have increased from 1.5 tonnes per hectare in 1960 to over 3 tonnes per hectare in 2000, while in Sub-Saharan Africa they increased from 0.7



tonnes per hectare in 1960 to 1 tonne per hectare in 2000. Although this increase of 43 percent is considerable, the gaps in yield of Africa compared with other continents has widened considerably over the past four decades.

Gaps in yield (attainable actual and potential actual) within Africa are far greater than the gaps cited between Africa and the rest of the world. Various crops typical for Africa when grown outside the continent produce higher yields. Sorghum, millet, rice, wheat and maize all respond dramatically to improved technology. Hybrid sorghums achieve yields exceeding 6 tonnes per hectare and top yields of over 10 tonnes per hectare are reported (NRC, 1996). Hence, technology already 'on the shelf' has the potential to enhance land productivity in Africa once adapted and fine-tuned to location specific situations. In the following subsections, constraints and opportunities to improved productivity of various crops and animals will be discussed. The most important crops in the four priority systems are maize, rice, sorghum, millet, legumes, cassava, yams, cocoa and coffee; important animals are cattle and goats. Most farming systems in Africa are based on a multitude of crops, often in combination with animals. Here the mixed cropping is studied at field level in an attempt to understand its complexity at farm level. The disappointing productivity trends for land, labour and inputs suggest that available technologies are not eagerly adopted by farmers. It is important to discover whether 'on the shelf' technologies can enhance the productivity of the majority of the African farming systems, or whether they are inappropriate and need adaptation.

The trends described above reinforce the general observation made in Chapter 3 – yield increases in Africa per hectare have not kept track with population increases. Where there are improvements to farming systems, they tend to be very modest, but there are exceptions. Egypt with its irrigated agriculture has had productivity increases similar to other irrigated areas in the world. However, in the rainfed systems, yields are increasing but not in pace with population increase. There is no simple explanation: low soil fertility and therefore very modest attainable yields; complicated systems with no applicable fine-tuned technologies; and pests, diseases and weeds that are reducing already very low attainable yields. This all leads to a bleak picture. However the potentials for improvement may be there. The lack of information on the production ecology of the systems, however, does not allow a comprehensive production ecological analysis.

New Rice for Africa (NERICA) Box 4.2

Scientists at WARDA succeeded in developing more than 3,000 progenies of interspecific hybrid rice by crossing a variety of *Oryza sativa* (common name: Asian rice) and a line of *Oryza glaberrima* (African rice). The interspecific hybrid rice was given the name of NERICA (New Rice for Africa). In field trials in West Africa yields increased by at least 35 percent. The feature of NERICA, which farmers most appreciate, is its short growing period of 90 days, allowing it to fit flexibly into a number of farming systems. NERICA also grows well with little input such as fertilizer or irrigation. These varieties, which combine the weed-control and drought-resistance characteristics of their African parents with the high-yielding characteristics of their Asian parents, are now being rapidly adopted in West Africa.



Rice

Rice production in Africa was 17 million tonnes in 2001, which is 14.6 percent of total cereal production in Africa. Consumption of rice has grown rapidly at an annual rate of 6 percent due to the change of lifestyle, particularly in urban areas mainly because rice is the most easily cooked food that can be prepared just by steaming. Further growth of consumption is expected. Average rice yields are still low in countries of Sub-Saharan Africa. Work by the West Africa Rice Development Association (WARDA) estimated the gaps in yields of rice cultivation in various rice ecologies (Table 4.1). The data suggest that up to 5 tonnes of yield increase per hectare is possible in some regions. It should be stressed that these yield gaps refer to the gaps observed under experimental field conditions. Yield gaps based on production ecological concepts may well be twice as high.

There is much scope to close yield gaps by some 2-4 tonnes per hectare in irrigated rice production in West and Central Africa (Table 4.1). Promising research avenues include development of low-cost water management, weed-competitive and nutrient-responsive rice varieties (Box 4.2), and site-specific soil fertility management. These actions address the current major biophysical factors limiting yields. An integrated rice management approach should raise production levels, optimize profits, preserve soil quality and protect natural resources. The step-wise integration of new technology options should take place with the full participation of farmers (Ndiaye et al., 2004).

About 40 percent of rice has been grown so far in upland rainfed conditions in West Africa. Since rice is a semi-aquatic plant, the yield is higher in lowland conditions than in upland conditions. In Africa, particularly in West Africa, there are vast areas of unused land in the inland valley bottoms, which correspond to the rainfed lowlands shown in Table 4.1. Such wet or flooded inland valleys are difficult to use for crops other than rice. Since the upland is competitive with the cultivation of upland crop species, it is preferable to grow more rice in the lowland inland valleys. Further exploitation of inland valleys with increased rice productivity is an urgent issue for food security, particularly in West Africa.

Maize

Maize is present in many African farming systems. Yield increases have however been modest overall, with greatest improvement in irrigated and commercial farming systems (Spencer, 2004). Introduction of improved maize germplasm has had a significant impact on maize production in



Table 4.1 Gaps in rice yields in various rice ecologies and relevant constraints to current production

Rice ecology	Maximum attainable yield at experimental field (t/ha)	Current yield (t/ha)	Yield gap (t/ha)	Constraints to current production
Rainfed upland	2.4-4.5	1	1.4-3.5	Weeds, acidity, blast, drought, nitrogen deficiency
Rainfed lowland	3.0-5.5	1.4	1.6-4.1	Weeds, water control, rice yellow mottle virus, nitrogen deficiency, drought
Irrigated	5.0-7.0	2.8	2.2-4.2	Nitrogen deficiency, weeds, rice yellow mottle virus, iron toxicity, nematodes, gall midge
Sahel irrigated	5.0-8.5	3.5	1.5-5.0	Nitrogen deficiency, cold, salinity, rice yellow mottle virus, alkalinity
Mangrove swamp	2.5-6.0	2	0.5-4.0	Sulphate acidity, salinity, crabs
Deep water/floating	1.5-3.0	1.2	0.3-1.8	Water control, low yielding varieties, low fertilizer use efficiency

Note: The yield gaps given in column four are measured as the rice yield attained at experimental/on-farm plots with no clear physical, biological and economic constraints and with the best-known management practices at a given time and in a given ecology, minus the average farmers' yield in a given target area at a given time and in a given ecology. *Source:* DeVries and Toenniessen (2001).

Africa. In favoured areas under farm conditions, hybrids have shown yield gains of at least 40 percent over local unimproved material (Smale and Heisey, 1994). In dry areas, hybrids have provided at least a 30 percent yield gain (Rohrbach, 1989; Lopez-Pereira and Morris, 1994). Especially notable is the rapid adoption of improved maize varieties in the savannah areas of Western Africa, particularly Nigeria, and important maize growing regions in Ethiopia, Ghana, Mali, Senegal and Zaire (Maredia et al., 1998). Breeding programs involving the International Institute for Tropical Agriculture (IITA) and The International Maize and Wheat Improvement Center (CIMMYT) have produced open-pollinated varieties, which in tropical areas have an estimated yield gain of 14-25 percent over local materials (Morris et al., 1992).

Apart from improved varieties, agronomic measures to improve soil fertility have led to dramatic yields improvements. Application of manure in



Zimbabwe, for instance, raised yield to more than 6 tonnes per hectare (Mapfumo and Giller, 2001). In West Africa, the Sasakawa Global 2000 initiative has introduced a package of improved maize technologies to increase productivity. Farmers were given management training plots of 0.25 hectare each and supplied with credit to purchase inputs (i.e., seeds of improved crop varieties, fertilizers and pesticides). The results are presented in Table 4.2. While yield increases are substantial, the variation in yield was also high (Brader, 2002).

Sorghum and millet

Sorghum and millet are drought-resistant crops of great importance for food security in the semi-arid tropical environments of Sub-Saharan Africa. They are generally grown in mixtures with other crops, primarily legumes. Though these cereals do respond dramatically to modern technology, farm yields are generally low, and progress has been limited.

There are suggestions that adoption of improved sorghum and millet varieties has been significant in some Southern African countries, notably Zimbabwe and Zambia. Much of the adoption in Southern Africa resulted from national and international research programs to disseminate improved varieties through drought relief programs (Rohrbach and Mutiro, 1996). In their review of constraints to sorghum and millet production in West Africa, Shetty and colleagues (1995: 249-265) show that all aspects of production need attention. Table 4.3 summarizes their findings, but does not indicate what technologies could be applied to realize the strategies. Basically, all technologies described in the next section can be utilized for this purpose, including genetic modification for developing desired variety characteristics, information and communications technology for decision support on management practices and integrated approaches to nutrient, water, pest, disease and weed management.

Table 4.2 Yield increase in maize due to the adoption of a technology package, comprising improved varieties, fertilizers and pesticides

Country	Period	Traditional yield (t/ha)	Average improved yield (t/ha)	Range of variation in improved yield (t/ha)
Burkina Faso	1996-2000	1.12	2.7	2.2 - 3.5
Ghana	1997-1999	1.48	3.6	3.3 - 4.8
Guinea	1999-2000	1.45	2.8	2.6 - 3.0
Mali	1998-2000	1.61	2.8	1.2 - 6.4

Source: Brader (2002).



Table 4.3 Constraints to and strategies for adoption of cereal production in the West African semi-arid tropics

Constraint	Factors	Potential strategies
Stand establishment	Moisture, temperature, sand storms	Superior varieties, tillage, ridging, crop residues
Drought	Drought during crop establishment and grain filling	Timely planting, correct planting densities, soil management, early and drought tolerant varieties, nutrient use, manure, genotypes
Nutrient stress (soil fertility)	Low inherent fertility	Timely planting, fertilization, rotation, intercropping, efficient nutrient use
Insects	Stem borers, panicle insects	Host-plant resistances, cultural practices, integrated pest management
Diseases	Downy mildew, smut etc.	Genetic resistance, integrated pest management
Weeds	Striga, and other annual and perennial weeds	Cultural practices, genetic resistance, integrated pest management
Traditional cultivars	Susceptible to stresses	Adapted and high yielding varieties with stability of production
Traditional management	No tillage, local varieties, low densities, minimal inputs	Improved management techniques, improved varieties
Consumer acceptance	Grain quality	Improved varieties with ease of dehulling acceptable for local products

Source: Shetty et al. (1995: 249-265). *Note:* Cereals include sorghum and millet. These strategies have been adopted by the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) and collaborating national agricultural research systems in the region.

Root crops

Root crops, which are generally capable of efficient production of calories under marginal soil conditions, account for over 50 percent of Africa's total staples on a volume base. A wide variety of root and tuber crops is grown – some such as potato are exotic and need good conditions for an acceptable yield. These crops are restricted to specific locations such as the highlands of Rwanda and Burundi. Others such as cassava perform and yield well under harsh conditions, having high tolerance to stresses such as drought. Their long harvesting period is an asset, providing a natural 'storage' environment.



Box 4.3 **Grazing land requirements and manure for arable farming**

Promoting the use of manure may support food production, but it must be realized that animals merely concentrate nutrients from surrounding areas to support the maintenance of the fertility of arable lands. Breman (1990: 227-294) showed that at least 15 hectares of rangeland and sometimes up to 40 hectares, is needed to sustain the feeding of one draught animal, breeding offspring and maintaining soil fertility in the savannah region of Mali. Increasing pressure on land for crops to feed a growing population means available lands for grazing will diminish, jeopardizing the sustenance of these systems. Breman (1995: 213-235) estimates that the carrying capacity is saturated in the northern Sahel, with a seriously over-populated southern Sahel and an almost saturated, locally heavily over-populated Sudanian savannah. The systems need supplementary sources of nutrients to prevent a negative spiral of degradation and poverty.

Pests and diseases cause production losses of root crops of over 50 percent. Average yields of cassava, potato and yam are 8-10 tonnes per hectare in Africa. With improved technologies, yield can be 5-10 times this average (Nyiiara, 1994: 50-55). The yield gap has not narrowed in the last decade due to lack of resources to invest in the soil to improve its fertility and the absence of supplementary irrigation to lower risks due to drought. Moreover, various diseases and pest cause considerable depression in actual yields.

In addition, attempts by farmers to market cassava products have fallen well short of their potential. Because it is highly perishable and contains toxic components, cassava needs special attention during post-harvest storage and processing. Processed products, and the enhanced importance of root and tuber crops as feed in the expanding meat production sector outside Africa, promise further development opportunities (Bruinsma, 1996).

Animal production

Animal production in many African countries contributes 20-30 percent of agricultural gross domestic product (AGGDP). In countries such as Botswana, Mauritania and Namibia, this may reach 80 percent (Abassa, 1995). Farmers in mixed crop-livestock systems are estimated to gain more than half their cash income from animals, and in some semi-arid regions ruminants are practically the only means of food production (Kaboré, 1994). Eleven percent of the African population totally depends on animals (Heap, 1994: 32-45). But current total meat production is inadequate to meet dietary needs, and Africa has a great trade deficit in livestock and livestock products (Abassa, 1995).

The place of livestock in African farming systems requires special attention. The major constraints to intensification in smallholder crop-livestock systems are nutrition, diseases and poor genetic potentials. There is a need for stronger institutions that understand and facilitate the smallholder intensification processes. Research opportunities include development of dual purpose (food-feed) crops, to meet human needs and provide improved nutrition for livestock; these must cope with climatic stresses during critical dry seasons and droughts. Other research opportunities lie in developments in livestock genetics and genomics. These make concepts – such as combining the hardiness and disease resistance qualities of many indigenous breeds of livestock with the productivity traits of many exotic breeds and the use of single vaccines to protect against multiple pathogens – likely realities by the year 2020.



Smallholders produce an extraordinary variety of livestock products, and the potential to improve their quantity, quality, range and dissemination is a major opportunity for poverty reduction at all levels. The challenges to, and opportunities for, improving the access of the poor to markets in livestock products are very much intertwined. High on the list are the sanitary and phytosanitary standards that govern trade in livestock products, affecting local, regional and international markets. Other research is required to improve food safety and develop better livestock policies.

The complexity of the livestock research agenda in Africa is illustrated by an in-depth analysis by Perry and colleagues (2002) of the priority diseases/pathogens according to their potential impact on the poor. They analyzed 76 candidate diseases/pathogens and found only 3 of the top 10 priority candidates were the same for the West African region and the Eastern, Central and Southern African regions (those are italicized in Table 4.4). The other seven in each region were different diseases/pathogens. This re-emphasizes the point that Africa deals with extremely diverse ecologies and biotic/abiotic constraints, which will require regionally mediated strategies, and only rarely continentwide ones.

The Perry study shows the opportunities for research that would help reduce losses from the diseases/pathogens. The most frequently cited opportunities are studies of epidemiology and of delivery/extension systems, followed by diagnostics, new vaccines, therapeutics and modified/test vaccines.

Some other issues relevant to livestock production are detailed in Boxes 4.3 and 4.4.

Lethal animal diseases constrain production

Box 4.4

Animal production is almost impossible in the hot and wetter parts of Africa, due to diseases such as trypanosomiasis (tsetse fly) (Agyemang, 2004) and the pressures of parasites (ticks, worms etc.). A focus on disease resistance has met with little success (Koudandé, 2000; Van der Waaij, 2001). Nomads and transhumants have learnt to use these infested areas for only a small period of the year to feed and water their herds.

In Africa, 37 percent of the continent (11 million square-kilometres and about 40 countries) is infested by tsetse flies (Murray and Trail, 1984). Control of the disease they carry, trypanosomiasis, could release about 65 percent of this area (7 million square-kilometres) for livestock or diversified farming without stress to the environment (MacLennan, 1980). About 46 million cattle are kept in tsetse infested areas – 17 million are treated with medication at an annual cost of US\$35 million. The potential benefits from trypanosomiasis control in terms of meat and milk surplus (added to benefits such as lower mortality and higher fertility) amount to US\$700 million per year (Kristjanson et al., 1999).

Table 4.4 The top ten livestock diseases/pathogens according to their impact on the poor

West Africa	Eastern, Central and Southern Africa
Anthrax	East coast fever
Black-leg	<i>Ectoparasites</i>
Contagious bovine pleuro-pneumonia	<i>Gastro-intestinal parasitism</i>
Dermatophilosis	Haemonchosis
<i>Ectoparasites</i>	Infectious coryza
<i>Gastro-intestinal parasitism</i>	Newcastle disease
Heartwater	Neonatal mortality
Liver fluke (fascioliasis)	Nutritional/micronutrient deficiencies
<i>Respiratory complexes</i>	<i>Respiratory complexes</i>
Trypanosomiasis	Rift valley fever

Note: Lists are in alphabetical order. Common pathogens and diseases in all regions are italicized. Source: Perry et al. (2002: 71).



Fisheries

Current regional supply of fish falls short of demand and future projections to 2020 indicate that the supply-demand gap will continue to grow (Ye, 1999). In Africa as a whole, per capita supply of fish is declining (FAO, 1999); in some countries the average diet contained even less fish protein in the 1990s than it did during the 1970s – the only geographic region of the world where this has occurred. There is considerable potential to enhance inland fisheries, but currently there are widespread concerns about over-fishing in inland waters, where habitats are degrading, water supplies are diminishing, and pollution is increasing. To sustain production there is a need for integrated approaches to river and lake-basin management and a focus on inland fisheries in planning and development.

The larger capture fisheries of Lake Victoria and floodplains, such as the Inner Niger Delta, are best known and best documented. But the widely dispersed smaller systems are more accessible to poor households, who depend on this source for animal protein, minerals and vitamins (Thilsted and Roos, 1999: 61-69). In eastern and southern Africa alone there are somewhere between 50,000 to 100,000 small water bodies (Haight, 1994).

Aquaculture must develop progressively to meet the projected increase in regional demand for fish protein. In addition, small-scale aquaculture could diversify livelihood options for poor farmers, increase income while reducing risk and vulnerability, and also lead to improved land and water management. For Sub-Saharan Africa alone, 9.2 million square-kilometres are suitable for smallholder fish farming. Only a fraction of these areas will be needed if fish harvests can reach the yields demonstrated on integrated farms (Kaptесky, 1995) – in Malawi and Zambia these yields are typically 1,500 kilograms per hectare per year (Brummett and Noble, 1995; Maguswi, 1994: 353-374). If only 1 percent of the almost 250 million hectare identified by FAO as suitable in southern Africa supported aquaculture enterprises, 3.75 million tonnes of fish per year might be produced. This is four times the reported catch from all capture fisheries in the region (Noble, 1996).

Small-scale farmers have stayed away from aquaculture because it is not yet effectively integrated into the farm economy (Harrison et al., 1994; Stomal and Weigel, 1998; Brummett and Williams, 2000). Technical impediments include lack of high-quality fingerlings; the lack of good quality, low-cost feed; insufficient means to control diseases as production intensity increases; and the competition for water. Integrated approaches, such as aquaculture with agriculture, result in a reliable supply of fish and additional income, improved overall farm profitability, rehabilitation of farmland, and improved drought resistance, while the increased crop production helps farmers prepare to deal with crises (Noble, 1996).



Crops important to Africa

Over recent decades there has been a heightened interest in various crops especially important to Africa such as legumes (cowpeas, pigeon pea, beans, and groundnut); roots and tubers (cassava, yams, potatoes); banana and teff. There has, however, been insufficient investment to identify their potentials and constraints (NRC, 1996). In addition to technical options, the limited international trade in these products may encourage regional markets to flourish, with little interference from international markets to suppress prices. Some crops have received virtually no sustained research. Elementary studies on teff, for example, have already shown enormous potential and await development. Box 4.5 describes the potential contribution of Africa's own rich biodiversity to the welfare of its people.

Box 4.5 Putting Africa's rich biodiversity to work

Africa is the origin or centre of diversity of several of world's most important crops, such as coffee, sorghum, lentil, wheat and barley, African rice (*Oryza glaberrima*), oil palm, yams and cowpeas. The huge biodiversity of Africa can still be further utilized with rational exploitation of forest products and byproducts, while proper conservation management is required to prevent genetic erosion. Biological diversity is fundamental for maintaining productivity and resilience of farming and livestock systems in marginal, risk-prone and diverse environments such as the drylands – a role that was underscored at the Earth Summit Conference (UNEP/CBD/SBSTTA, '99). In general, there is a positive relationship between species richness and productivity, and ecosystem resistance to drought (Tilman, 1997; Hector et al., 1999).

There are some successful cases of conservation and sustainable use of natural resources in developing countries, which have not been sufficiently publicised until recently, such as the recent compilation by Lemons and colleagues (2003). One prominent program is the Matrouh Resource Management Project in the semi-desert area of northwest Egypt, which aims to break a cycle of natural re-

source degradation (El Mourid et al, 2004). Adaptive research was undertaken there to improve the management of natural rangeland and to identify and study pertinent local species (annuals and perennials), followed by multiplication and distribution to farmers. Improved practices for seedling production of fodder shrubs and for transplanting and management were promoted. Impressive results were also obtained in central Tunisia (20-300 millimetres rainfall) by planting fast-growing shrubs (*Acacia cyanophylla*, *Atriplex nummularia*, *Opuntia ficus-indica*) (Nefzaoui, 2004). In south Tunisia (100 millimetres rainfall), these species were used in association with water-harvesting techniques. The possibility of utilizing slow-growing native shrubs is an alternative and deserves serious investigation – technical, social, and economic.

In the Sahel, a great deal of comprehensive research has been undertaken on bio/agrodiversity (see, for example, *Danish Journal of Geography*, special issue volume 2, 1999). Significant international ex situ collections of genetic resources have been built up by the International Crops Research Institute for Semi-Arid Tropics (ICRISAT) (IPED, 1994) and other institutions such as the

Semi-Arid Tropics (ICRISAT) (IPED, 1994) and other institutions such as the Royal Botanical Gardens, Kew, particularly in its Survey of Economic Plants for Arid and Semi-Arid Lands database. In the dry lands of west Africa, most species are very resilient to the combined pressures of climate fluctuation and seasonal grazing. Some are drought-escaping species, fast growers, and particularly efficient in using water during early stages of the life cycle; others are slow growers, with a long growing season and a 'strategy' of conservative use of available water resources for survival (Maroco et al., 1997; 2000).

The diversity of Africa's biological resources is not an end in itself but a means of alleviating poverty, achieving food security and conferring 'stability' and resilience to the environment. However, Africa's genetic resources are inadequately known, valued and utilized. And the genetic base of Africa's agrobiodiversity is being eroded due to the unbalanced exploitation and the increasing competition for natural resources due to an increasing population. Concern about loss of diversity is a major driver for inclusion in several international agreements, notably the Convention on Biological Diversity (CBD).



Box 4.6 Agroforestry

Agroforestry offers the promise of increased agricultural productivity and natural resource protection while increasing diversity and socioeconomic stability (Franzel and Scherr, 2002). In marginal areas, agroforestry trees can supply farm households with a wide range of products for domestic use or sale, including food, medicine, livestock feed and timber. Trees also bring environmental benefits such as increased soil fertility and moisture conservation, and social services, such as boundary markers (Franzel et al., 2001). Agroforestry can be of importance when periods in traditional bush-fallow systems become too short to restore soil fertility. There is great potential to improve the productivity of traditional cropping systems, but studies reveal that the system has great diversity and complexity that necessitate specific measures. In part because of this specificity, Franzel and colleagues (2001) suggest that a farmer-centred approach would ensure development, adaptation and adoption of agroforestry practices.

Sanchez (2002) describes how agroforestry can contribute to soil fertility replenishment. In the bimodal rainfall areas of East Africa. Farmers establish rotations of one year of leguminous trees followed by one year of maize. In the unimodal rainfall areas of southern Africa, two years of trees are grown followed by 2-3 years of maize crops. The legumes enable accumulation of 100-200 kilograms of nitrogen per hectare over a period of 6 months to two years, and this is available for the maize. Yields of maize increase two- to four-fold, making these fallow periods with leguminous trees economically and ecologically sound. As the technique was developed with farmers, they fit well with farmers' customs and work calendars, but Sanchez has warned of limitations to applying this approach more widely, because of the strong location specificity (see also Lompo, 1993).

Adapting technologies to farmers' needs

Smallholder farmers in Africa manage their environmental diversity by matching crops and crop mixtures to the variations in the bio-physical environment, resulting in farming systems that involve 10-15 food and cash crops in a wide array of mixtures. The earlier descriptions of the farming systems indicated the need for interventions at all production ecological levels to generate productivity increases. The diverse conditions of the African continent demand specific measures, and the following sections focus on integrated and technological approaches to overcome constraints.

Integrated approaches

Integrated approaches search for the best use of the functional relations among living organisms in relation to the environment, without excluding use of external inputs. Integrated approaches aim at the achievement of multiple goals (productivity increase, environmental sustainability and social welfare) using a variety of methods. Food can for instance be produced with minimal adverse effects on the environment, and therefore without harming the functions of other ecosystems. The combination of integrated pest and disease management, integrated water management and integrated nutrient management offer considerable promise. Integrated pest management in rice cultivation provided one of the first examples of the use of integrated approaches, with its reliance on natural predators and parasites, allowing a reduction in the application of pesticides. Integrated nutrient management exploits the functional relations between systems (e.g., by restoring nutrient balances in order to reduce soil fertility decline or to even improve soil fertility, while reducing contamination). Integrated water management aims to increase water use efficiency using a variety of approaches.

Integrated water management

Water scarcity is one of the greatest limitations to crop expansion outside tropical areas in Africa (Ait Kadi, 2004). Therefore, even modest improvements in crop resistance to drought and in water use efficiency will have significant productivity and economic impacts. Globally, irrigation plays a pivotal role, accounting for 40 percent of food production on 17 percent of the agricultural lands. Rosegrant and Perez (1997) argue that the bulk of global food production increases in the future will come from irrigated agriculture.

That may hold globally, but most of the world's poor, especially in Africa, produce food under rainfed conditions (see Table 3.3 in Chapter 3). Much



more can be done to improve water use in arid and semi-arid regions. Water use efficiency under these conditions could be 3 to 4 times higher than current values (Bindraban et al., 1999). These assessments are confirmed by field observations. Comparable gaps of three-to four-fold between actual and attainable yields have been reported from semi-arid regions in the Mediterranean (French and Schultz, 1984); Eastern Africa (Smaling et al., 1992); Sub-Saharan Africa (Rockström, 2001); Sahel (Bremen et al., 2001); Southern India (Ahlawat and Rana, 1998) and Western China (Li et al., 2001).

There is increasing evidence from Asia that research and development (R&D) investments in rainfed areas offer win-win outcomes, in terms of both productivity growth and reductions in poverty, far in excess of similar investments in irrigated agriculture (Fan et al, 2000a; 2000b). Yield gaps in rainfed areas are often higher than in irrigated areas, and hence the return to further research and development and infrastructure investments can be higher. While irrigated areas have traditionally had higher adoption rates of modern varieties of crops than rainfed areas, there is accumulating evidence that rainfed areas in Sub-Saharan Africa have average adoption rates that are now approaching those of irrigated areas in Asia in the 1980s (Evenson and Gollin, 2001).

Drought risk, however, impedes investments, causing production to stagnate at subsistence levels with low water-use efficiencies. Climate change is expected to further exacerbate these risks. Resolving water scarcity problems requires an integrated water resource management approach (Box 4.7). The understanding of water cycles and related linkages between societal sectors is weak. Conflicting goals remain unresolved and fundamental trade-offs are not made explicit. The conventional, compartmentalized supply-oriented approach cannot cope with aspects of linkages between water, land-use and ecosystem demand in the context of socio-economic development and environmental sustainability (Ait Kadi, 2004).

A supply management strategy and a more rigorous demand management strategy (involving comprehensive reforms and actions to better use existing supplies) are both needed to avert water scarcity that impedes agricultural development. The sustainable use of water resources calls for an enabling political, legal and institutional environment to transcend traditional boundaries between sectors and involve a variety of users and stakeholders using a catchment approach. With agriculture being by far the largest user of water, improving water-use efficiency will remain a key dimension in resolving water scarcity problems. Issues of poor utilization, deteriorating quality and shortages can be addressed, and cross-boundary issues should be resolved.

The challenge of integrated water resource management

Box 4.7

Research in Egypt, Ghana, Morocco, South Africa and Tunisia shows the disparity between integrated water resource management at the policy level and in reality. Policymakers are focusing on watershed-level issues in the sectors of drinking water, hydropower, agriculture (including irrigation), industry, nature and recreation. One difficulty is that agencies come under different ministries that are not accustomed to working together.

Therefore, integrated water resource management is not having much impact at the field level. For example, rules that forbid discharge of wastewater into open water systems or its reuse in agriculture are routinely ignored when there are no alternatives. Similarly, rules that prohibit irrigation canal water from being used for drinking, bathing, laundry, or discharging wastewater are disregarded when drinking-water supplies and sewage systems are absent.

It is clear that in addition to the technical water aspects, organizational, social, cultural and economic elements at the local level have to be addressed for successful implementation. A one-issue approach has to be replaced by an integrated-development approach (Boelee, 2000; Warner and Simpungwe, 2003).



Integrated nutrient management

Specific agronomic interventions are needed for the large diversity in soil characteristics that prevail in each locality. Low fertilizer application rates in African countries, reaching only 11 kilograms per hectare of harvested land compared with a world average of 96 kilograms per hectare (FAO, 1999), favour the use of organic fertilizers, such as manure and legumes. (Use of legumes is discussed in Box 4.8.) Current soil nutrient depletion rates, due to increased pressure on the land for food production, warrant an integrated approach to maintain soil health.

Numerous studies reveal a synergistic effect of inorganic and organic fertilization on soil and crop productivity, while neither component in itself shows sustained long-term improvements (Ahmed et al., 2000; Ahmed and Sanders, 1998; Bationo et al., 1998). Also, Giller (2001) points out that the role legumes can play varies between systems, due to strong environmental effects on nitrogen fixation.

Box 4.8 Legumes and plant-bacteria associations

Legumes are a major source of nitrogen to non-legume crops in mixed cropping systems. While there is a good understanding of the processes involved in biological nitrogen fixation, much less is known about the transfer of nitrogen to the companion or succeeding non-legume crop. Better insight is needed into overall balances of nitrogen and transfer processes in the soils, in the context of the whole system. Between 50 and 300 kilograms of nitrogen per hectare can be fixed by legumes. Plant breeders have learnt to manipulate nitrogen fixation so that the proportion of legume nitrogen derived from nitrogen fixation is always well in excess of the proportion of legume nitrogen harvested in the grain.

The amount of nitrogen left in the residuals represents that portion available to other crops. Estimates of nitrogen transfer to a companion non-legume range from 25 to 155 kilograms per hectare. This wide range indicates the complexity of the many factors that impact on nitrogen transfer and reveals the incomplete understanding of the processes involved. Indirect transfer to succeeding crops is likely to greatly exceed that of di-

rect transfer to companion crops. Direct transfer of nitrogen from legumes to non-legumes may not exceed 10 percent of nitrogen.

In addition to providing nitrogen to the cropping system, legumes are natural partners of cereal, root and tuber crops in intercropping. Benefits are obtained through soil fertility improvement, erosion control and weed suppression (Asafu-Agyei, 1994: 233-236). One benefit of legumes often mentioned is their high-quality straw for animal feed and high protein to balance human diet.

Giller (2001) stresses that 'growing legumes solely to improve soil fertility is just not worth the effort.' Therefore, multi-purpose legumes must be identified to enhance their adoption by farmers. For extended examples on the use of legumes, see Giller (2001). At the same time, successful examples are available from other continents.

Plant breeding technologies have enhanced bio-fertilization (e.g. through biological nitrogen fixation), boosting soybean production in Brazil and Argentina without nitrogen fertilizers. In addition to nitrogen fixation, bacteria can make

phosphorus from rock phosphate more soluble, making it available for uptake by plants (Raven et al., 1990; Dobreiner, 1994: 66-77).

In addition to fixing nitrogen and making rock phosphate more soluble, bacteria can form natural plant – bacteria associations that protect crops against attack by pathogens, thus limiting crop losses due to disease and enhancing yields (e.g., Bashan, 1998; Dobbelaere et al., 2001; Ratti et al., 2001; Rueda-Puente et al., 2004). Biocontrol and plant growth promoting rhizobacteria are subject to ecological factors, much like any other approach that makes use of natural biological resources. Especially in biophysically stressed ecosystems, the use or stimulation of microbes can just 'make the difference' for crops to perform adequately or to fail. The gains in crop performance by naturally occurring nitrogen fixing bacteria are found by Dobreiner in Brazil in ecological conditions very akin to parts of Africa. Such microorganisms therefore hold the prospect of benefiting sustainable agricultural production in Africa.



Deposits of rock phosphate are useful in eliminating phosphorus deficiencies, which are particularly widespread in East Africa and the Sahel (Van Straaten, 2002). The mild acidity of soils (pH 5-6) in Western Kenya helps to dissolve high-quality rock phosphate, supplying crops with adequate amounts of phosphorus for several years and doubling or tripling maize yields (Sanchez, 2002). Phosphorus deficiency is the most limiting factor for legume productivity in tropical soils (Franco and Munns, 1982). Africa's resources of rock phosphate in combination with zero tillage may be used to break through the low soil organic matter and increase soil productivity (Sisti et al., 2003). Often the availability of high-reactivity rock phosphate is limited, and the effectiveness depends on numerous conditions, such as soil pH and water status. Thus exploitation and application depend on individual circumstances.

The spatial variability of soils requires special attention in integrated nutrient management. Variability is large at regional level and also in farmers' fields. Brouwer and Powell (1998) showed close relations between micro-topographic characteristics of the field and relative wetness and leaching of nitrogen and phosphorus. They indicated that more efficient use can be made of scarce, locally available resources of manure and urine, when application rates are attuned to the variation in the field. Simple procedures such as scoring techniques will capture the variability in yield for guiding spatial application (Gandah et al., 2000). Hence, the principles of precision agriculture can be applied through advanced technologies of satellite-based geo-referenced machines, but also through visual assessment of the micro-topographical characteristics by farmers in their fields.

Integrated approaches bring benefits in the long-term, by preventing both physical and chemical degradation of soils (the typical characteristics of unsustainability) while simultaneously achieving short-term productivity gains. Targeted interventions such as a voucher system for poor farmers to acquire small packs of fertilizers through traders have little distortionary impact on the market, while stimulating fertilizer use (IFDC, 2003).

Integrated pest and disease management

Integrated pest management in rice cultivation was one of the first attempts to exploit the functional relations between organisms within an ecosystem. The need for integrated pest management arose because farmers in the 1960s received a package deal – improved seeds and pesticides – that encouraged them to protect their improved varieties. The need for protective measures remained high, resulting in excessive spraying of pes-



ticides, which undermined the effectiveness of the ecological prey-predator system in the rice fields.

The emergence of integrated pest management and farmer education has led to success in reducing pesticide use, while maintaining high yields. At farmers' field schools pioneered by FAO, farmers and scientists share their knowledge about the predator or pathogen, its lifecycle, its impacts etc., with the objective of improving the timely discovery of infestations and taking adequate measures. It is stressed that there is no ban on the use of biocides (environmentally friendly pesticides) under these systems. Integrated pest management now represents a means for efficient pest control and reduction of pesticide use. It is promoted by major agricultural and development institutions and was adopted by the United Nations conference on environment and development in 1992 (Agenda 21, Chapter 14, sustainable agriculture and rural development).

The upgrading and updating of such integrated pest management systems is always needed. Some preliminary examples in Africa are available, but need upscaling and continuous upgrading. The CAB International Integrated Pest Management Facility, Consultative Group on International Agricultural Research (CGIAR), FAO, United Nations Development Program (UNDP), United National Environment Program (UNEP), World Bank, as well as nongovernmental organizations, many governments and other institutions in Africa have adopted integrated pest management as policy. Opportunities for integrated pest management among smallholder farmers in Africa are expanding because it is enabling resource-poor farmers to maintain and sustain high agricultural productivity. For example, the strategies to control the parasitic weed *Striga* are described in Box 4.9.

Suppression of weed infestation to reduce yield losses can also be achieved through agronomic measures. Consider, for example, minimum tillage, which in essence consists of planting a crop with minimal disruption of the soil (e.g., no plowing or groundbreaking). While it is primarily seen as a means of soil protection and fertility conservation, minimum tillage appears to be an effective way of controlling weeds as well because the non-disturbance prevents seed banks of weeds from being periodically incorporated into the soil. This ancient indigenous technique is thus making a comeback. No tillage is being used in at least 21 million hectares of cropping land in South America at a growing pace of 5 percent a year.



Breeding and biotechnologies

Biotechnology, including applications like tissue culture, marker-assisted selection, as well as genetic modification involving recombinant DNA technology, has opened up uncommon opportunities for improving the productivity, quality and sustainability of crop and animal husbandry, fisheries and forestry. Conventional biotechnologies have been in use for a long time, while genetic modification technology is of more recent origin beginning with the discovery of the double helix structure of DNA by Watson and Crick in 1953.

Tissue culture makes use of the totipotency of cells and has had an enormous impact on plant breeding over the last decades. Propagation of elite material, virus free meristeme cultures, somatic hybridization, dihaploid plants and hybrid breeding are amongst the most significant applica-

Box 4.9 Multidisciplinary fight against Striga

Striga species, or the witchweeds, are parasitic weeds of cereal grain crops and some legumes in Sub-Saharan Africa. The most important species, *S. hermonthica*, alone infests approximately 20-40 million hectares of farmland cultivated by poor farmers and is responsible for lost yields valued at approximately US\$1 billion annually. An estimated 100 million farmers lose from 20 to 80 percent of their yields to this parasite. Striga's complex lifecycle and the intimate interaction with a host plant make control very difficult. The complexity and huge impact of the Striga problem suggest that all means, including a genetic modification approach, need considering as part of an acceptable solution.

An example of a mono-disciplinary but promising approach is the use of an herbicide-resistant maize variety that is currently being tested for resistance to Striga in Kenya. The maize seeds are coated with the herbicide before planting. Once the seeds germinate the parasites unwittingly devour the weed-killing chemical from the crop roots or surrounding soil and die (Friesen and Gressel, 2002). The experimental results below show the effectiveness of seed coating on IR-maize on yield increase (CIMMYT, 2003). At an effective cost of US\$4.00 per hectare (equivalent to about 25-50 kilograms per hectare of maize yield, depending on market prices) a potential benefit-cost ratio in excess of 25:1 can be obtained, even under the least favourable conditions.

Effect of imazapyr-coated IR-maize seed on grain yield in Striga-infested fields on station.

Herbicide	Herbicide rate (gs/ha)	Grain yield (tonnes/ha)
Control	0	0.93
Imazapyr	30	3.06
Imazapyr	45	3.39

Effect of imazapyr-coated IR-maize seed on Striga control and grain yield on farmers' fields.

Herbicide	Herbicide rate (gs/ha) 12 weeks after planting	Striga plants/m ²	Grain yield (tonnes/ha)
Control	0	23.2	0.55
Imazapyr	30	4.0	2.50
Imazapyr	45	1.4	2.72



Box 4.10 African Agriculture Technology Foundation

The African Agricultural Technology Foundation (AATF) is an African-led and African-governed, not-for-profit entity. The AATF helps public research institutions in Africa access the proprietary technologies and know-how that they could not otherwise acquire due to restrictive patenting or licensing practices. Potential technologies that might come from private companies and other sources include biological, chemical and mechanical processes.

Funded by The Rockefeller Foundation, Department for International Development (United Kingdom) and United States Agency for International Development, AATF brokers royalty-free transfers of useful technologies between intellectual property owners and research institutions, with the objective of developing technologies that meet the needs of resource-poor African farmers. Once finished technologies are available, the AATF ensures that all regulatory requirements are satisfied. It then enters into contractual agreements with appropriate partner institutions to ensure that obstacles to successful dissemination are identified and adequately addressed, such that the new products actually get into the hands of poor farmers. With its headquarters in Nairobi, the AATF's mandate covers Sub-Saharan Africa. The AATF was registered in 2002 in the United Kingdom and Kenya as a private limited company, and operations began in 2003.

tions. Tissue culture has also opened the way for genetic transformation, leading to genetically modified organisms (GMOs).

Genetically modified organisms involve novel genetic combinations arising from the transfer of genes from unrelated species across sexual barriers. Thus it has become possible to introduce genes from a wide range of species and genera irrespective of their ability to undergo sexual hybridization. During the last 20 years numerous GMOs of great interest to agriculture and medicine have been developed. The science of genetic modification is making very rapid progress.

DNA technologies lead also to powerful non-GMO applications. New high-throughput technologies in the field of genomics, transcriptomics, microarrays, proteomics and metabolomics generate an enormous amount of data and, when interpreted correctly, lead to a profound knowledge of genome structure and functioning. This knowledge is already widely used by companies and research institutes for identifying target genes that can be isolated for use in genetic modification or followed in conventional breeding programs to increase the selection efficiency (marker-assisted selection).

The Green Revolution in cereals was essentially a product of public sector research. The gene revolution based on GMOs, in contrast, is being triggered by private sector industry. Since the choice of research problems by the private sector will be largely determined by commercial opportunities, there is need for a strong public sector commitment to harnessing biotechnology for addressing the problems of marginal rainfed areas and of resource poor farmers. For example, there is need for greater public investment in developing GMOs possessing tolerance to drought, salinity, other forms of abiotic stresses, as well as resistances to biotic stresses such as pests and pathogens (e.g. Kiome, 2004; Thomson 2002).

Due to the fact that much of the GMO research is done in the private sector, technologies are very often subjected to intellectual property rights. These may hamper the application of technologies for African agriculture. This is acknowledged by leading biotechnology companies around the world. Box 4.10 describes a new institutional innovation aimed at facilitating public-private partnerships in biotechnology in Africa.

In the case of agricultural and food biotechnology there have been concerns about food and environmental safety. The Cartagena Protocol on Biosafety provides some internationally agreed guidelines for the safe and responsible use of biotechnology in crop improvement. There is need for regulatory mechanisms which can inspire public confidence with reference to benefit-risk assessment of GMOs.



African agriculture should derive maximum benefit from both classical plant breeding and biotechnology. It will be useful to set up advanced research centres to undertake basic research leading to the development and use of novel genetic resources. Such research centres could provide new genetic material and methods to national agricultural research systems for inclusion in their breeding programs, thereby leading to the development of location specific crop varieties. Some examples of prospective biotechnological processes and products are contained in Boxes 4.11 and 4.12.

Capacity building in the development and administration of biosafety procedures is urgently needed. This is being addressed by the United Nations Environmental Program and the linked Global Environment Facility. There is also need for a public genetic literacy campaign on the implications of GMOS for crop and food security.

In the choice of research tools, preference should be given to those tools that can help scientists to achieve their goals speedily, surely and economically. One should not worship a tool because it is new, nor should one discard a tool because it is old. What is important is the choice of a right mix of research tools and strategies that can help resource poor farm families to obtain higher yields at lower cost and with better quality.

Information technology

Rapid developments in information and communication technologies have changed the world dramatically. Collection, processing and dissemination of huge amounts of data have become feasible. Information technology has stimulated the development of comprehensive computation

Box 4.12 Application and adoption of biotechnologies

Farmers' adoption of crops resistant to insects and herbicides

In 1997 a few farmers in the Makhtini Flats area of Kwa-Zulu Natal, near the Mozambique border planted insect-resistant Bt cotton. One farmer planted half his 4-hectare farm with it and half with traditional cotton. The genetically modified cotton yielded twice as much as the traditional. He took the cotton to the annual farmers' day where the effect was dramatic – nearly 80 farmers planted genetically modified cotton the next season. In 2003 that number has expanded to over 2,000 farmers.

Successful propagation

Low-cost and low-risk biotechnology techniques (such as micro-propagation) can enable rapid increases in yield. For example, disease-free plantlets can be produced for high-value commercial crops. A remarkable success story for tissue culture is the development of improved banana cultivars in Kenya. Small-scale farmers adopting the technology can raise their yields around 130 percent (Wambugu, 2001). Tissue culture is also appropriate for staple food crops such as cassava.

Some promising biotechnologies Box 4.11

A new strategy to engineer rice plants with a sugar-producing gene helps them tolerate drought, salt and low temperatures, while improving their yields. The chemical composition of the rice grains remains unchanged. The same strategy should also work in a range of crops including corn, wheat, millet, soybeans and sugar cane (Garg et al., 2002).

In Egypt, transgenic cultivars of major crops of economic importance are being developed, such as virus-resistant cucumber crops, Gemini virus-resistant tomato, tuber moth-resistant potato (Madkour, 2004).

Scientists in South Africa are using genetic modification to develop maize resistant to the African endemic Maize streak virus and tolerant to drought and other abiotic stresses.

Marker-selected breeding is being used by scientists at CIMMYT to develop drought-tolerant maize and wheat. Scientists in South Africa are using genetic modification to develop maize tolerant to drought and other abiotic stresses.

In root crops, Kenya and Nigeria are considering application for controlled tests of transgenic cassava plants with resistance to African cassava mosaic virus.



models, like models of crop and animal growth. Improved communication technologies have spurred information flow and virtually eliminated time lags in information transfer. Timely availability and access to information at any location, irrespective of the distance, provide better means to anticipate developments, such as market information on prices, but also early warnings on insufficient food availability due to crop failure. Those without access to such rapid communication are pushed into isolation (e.g. Salih, 2004).

As with breeding and biotechnology, information technology can assist agricultural production practices to overcome the gaps between the actual and attainable yield and between attainable and potential yield, and to increase the potential yield level. Rapid, effective information processing and management can help agriculture. Some examples are resource allocation, crop and animal production modelling and improved resource-use efficiency. In addition there is a strong need for risk-reducing information such as for the Sahalian zone. Agro-ecological analyses may reveal substantial production potentials (Bindraban et al., 1999; 2000), but risk-reducing information is vital for farmers considering use of new technologies, such as drought-tolerant crops (Jagtap and Chan, 2000). Decision support systems for strategic, tactical and operational decision-making are needed to supply such information. The whole arsenal of new information and communications technologies, such as remote sensing, geographic information systems (GIS) and crop and climate modelling, can be employed for this purpose.

Mechanizing operations

‘The man with the hoe’ remains an apt description of the average African farmer today, just as it was 40 years ago. This situation must be changed; greater availability of machinery and other modern equipment is imperative. In every link of the long agricultural-production-marketing chain – seedbed preparation, planting, weed/pest/disease control, breeding, feeding, harvesting, processing, preservation, storage, transportation/distribution, marketing, and even cooking – appropriate levels of agricultural mechanization can provide the tools by which the inherent drudgeries and inefficiencies can be removed and productivity accelerated and enhanced (Odigboh, 2002: 225-300). An additional reason for more mechanization is the shortage of labour resulting from HIV/AIDS, which is decimating the younger generations.

Mechanization had an enormous impact on labour productivity in many countries. Roseboom and colleagues (2004), for instance, show significant



growth in agricultural productivity in most regions in the world, with the exception of southern, eastern, and western Africa, where progress in labour productivity has been dismal over the past 40 years (see also Figure 4.1). Almost 100 percent of the land in Europe and North America is cultivated by mechanical means, as opposed to 40-70 percent in Asia and Latin America. In Africa, only 1 percent of the land is worked mechanically; animal draught covers 10 percent and manual power is employed in 89 percent.

To increase labour productivity, an effort should be made to significantly enhance the use of mechanized power in Africa. While mechanization is not a panacea for productivity increase, it is a strategic option that should be applied whenever appropriate (Le Thiec, 1996; Fauré, 1994). South Africa has experienced significant productivity increases, predominantly in the commercial farming sector. Maize yields have tripled over the past four decades. Large increases in land and labour productivity have been evident in Nigeria as the labour force employed in primary agriculture dropped from 71 percent in 1970 to 33 percent in 2000, and the government took several macroeconomic measures to stimulate agricultural production – for instance, a ban on agricultural imports and subsidized agricultural inputs.

The process of mechanization to further increase land and labour productivity worldwide has not come to an end. The possibility to continuously increase land and labour productivity is present and stimulated by the need to maintain an economically viable position in market-driven societies.

Although the mechanization process has virtually just begun in most of Africa, progress is often slowed by the fact that most African countries rely on imported technology – many forms of mechanization are not yet appropriate to African agriculture simply because they are not known by, or not of sufficient priority to, American, European, and Asian machinery makers. In addition, machines are not usually equipped to handle mixed cropping systems that are a feature in Africa. Finally, most imported agricultural machines are so technically complex and costly that they are beyond the financial reach and managerial ability of the majority of African farmers.

Another factor is that the appropriateness of implements for use by women is generally overlooked (IFAD/FAO/GOJ, 1998). Women's contribution to food-crop production ranges from 30 percent in the Sudan to 80 percent in the Congo, while their proportion of the active labour force in agriculture ranges from 48 percent in Burkina Faso to 73 percent in the Congo. A basic problem is that heavy implements, such as the ox-drawn five-tine cultivator built in Zimbabwe, are very difficult for women to use. Most report that they cannot handle this cultivator when turning and cannot turn the lever that adjusts its working width. They also complain about the zigzag harrow, say-



ing that they cannot lift it around obstacles. There are also many complaints by ‘the woman with the hoe’ that this standard implement, designed for men, is just too heavy for her to use efficiently. Given the African proverb ‘Without women we all go hungry,’ feminization of agricultural implements is necessary. Meanwhile, it is ironic that only five percent of the resources provided through extension services in Africa are available to women. A priority task for scientists is to develop technologies that can help to reduce the hours of work and increase income per hour of work of women.

A pragmatic solution is proposed for increasing the use of machines and other implements. Suitable indigenous firms and organizations should be encouraged to do the local manufacturing of machines and equipment for agriculture and rural industrial activities, possibly in partnership with overseas manufacturers. Only in this way will the machines needed for the specific African situation be developed. Further, local production and maintenance will be more cost-effective.

Exploiting post-harvest opportunities

Proper storage can prevent much loss in quantity and quality of the harvest (see Figure 3.4b, Chapter 3). Maize is generally stored in traditional granaries for food and feed and for sale. Losses in excess of 30 percent over short storage seasons are not uncommon. Chemical control strategies work but are rarely used because of economic constraints, environmental damage and adverse health effects (even deaths have been recorded from misuse). As damage generally has multiple causes, integrated pest management approaches have good prospects for controlling post-harvest storage losses, such as in maize (Adda et al., 2002). Produce quality is also strongly related to storage practices, as has been shown with aflatoxin contamination in maize (Hell et al., 2000). Feed storage is necessary also to improve livestock production.

Proper storage and high-quality processing is of importance to generate export opportunities for African produce. Current sanitary and phytosanitary standards may restrict access to foreign markets due to increasing demands for food safety by wealthier consumers. However, illegitimate use of such standards as non-tariff barriers must be prevented. Otsuki and colleagues (2001) for instance shows that stricter European Union standards of aflatoxin compared to those set by the international standard of the Codex Alimentarius Commission will reduce health risk by only approximately 1.4 deaths per billion per year, while decreasing exports from Africa



by 64 percent, or us\$670 million. In defining standards, Henson and Loader (2001) argue that more effective participation of developing countries is needed where developed countries have to take special circumstances of developing countries into account. In addition, developing countries need to implement institutional structures and procedures to enable producers and processors to comply with the necessary standards.

Part of the agenda for enhancing agricultural productivity will require increased processing of agricultural products into finished products for domestic consumption and for export, so that market constraints do not prevent turning it into added value and profits. There are a number of constraints to developing agro-processing industries in Africa. First, expert knowledge, entrepreneurship and management skills are needed. Next, the infrastructural facilities (power, water, communication, etc.) are inadequate in most African countries. Third, agro-processing cannot rely on subsistence agriculture for the needed raw materials – an inadequate supply of agricultural products of uniform quality hampers development. Efficient mechanized and commercial production units are needed to provide a steady supply of primary agricultural products. Last, the machinery needed for processing is not available. Local research and development activities concentrate mainly on relatively simple technologies without breaking new ground. The interest or capability to engineer and develop sophisticated machinery is often lacking.

The considerable knowledge about such activities present in the industrialized world and in commercial food companies is needed to help African-based retail and processing firms. Improvements in post-harvest technologies, including sorting, grading, packaging, cooling and storing, are urgently needed (Ki-Munseki, 2004) to develop a sound processing industry.

Improving nutrition through agriculture

Both the quantity and the quality of food items must be addressed in resolving food insecurity. Conventional breeding and selection has increased the content of pro-vitamin A in orange-fleshed sweet potato and orange or yellow cassava. After only two cycles of selection and recombination, the concentration of beta-carotene in cassava increased from 4.2 milligrams per kilogram of fresh roots in a base population to 14 milligrams per kilogram (Graham et al., 1999). Similar techniques reduced the concentration of phytate in barley, maize, rice and wheat. Anti-nutritional factors such as phytic acid or tannins cause complexes with micronutrients, reducing



their availability for human uptake in several cereals to only about 5 percent of the available micronutrients.

Germplasm improvement has also contributed to improved diets through Quality Protein Maize (QPM), containing more lysine and tryptophan, which is being disseminated in Africa, in particular in Ghana. Quality Protein Maize is used for weaning diets and in poultry and pig feed. Normal maize protein is deficient in these two essential amino acids, which can be supplemented by consuming milk, meat or beans. As the latter option is often not within the reach of poor families, Quality Protein Maize can improve the health of people and livestock. Consumer preference for relatively soft grain maize has contributed to the success of Quality Protein Maize in Ghana (CIMMYT, 2002). Quality improvement of grains with respect to specific characteristics should be balanced with the possible trade-offs in terms of yield, disease and pest resistance and consumer acceptability.

Various initiatives are underway to increase the nutritive value of food crops, including high-iron beans, high-betacarotene maize, high-iron rice, high-vitamin A or golden rice and orange-flesh sweet potato in the Biofortification Challenge Program of the CGIAR (CGIAR, 2002).

Various agronomic measures can improve the nutritive value of some food crops. Application of zinc to the soil increases grain zinc content in cereal crops by a factor of two to three, depending on species and crop genotype. Application of zinc and phosphorus led to increased yield and also increased the amino acids methionine and lysine in wheat grains in Bangladesh (Graham et al., 1999).

Medicinal plants are emerging as medical aids for health maintenance all over the world. The global market for medicinal plants is expected to grow considerably in the coming decade. Europe accounts for the largest part of this market. So conservation and propagation of medicinal plants in farms and parks is required. Besides the impact on local health care and nutrition, cash crops of pharmaceutical and nutraceutical plants can have a positive impact on creation of jobs and local capacity building, such as it has happened in Brazil, Morocco and South Africa.

Broadening of objectives and diversified systems

Reviews of productivity increases in Africa reveal that the largest improvements occurred in sole crop fields. These findings are in line with the global model of increased specialization to increase productivity, implicitly suggesting that the transition from diversified systems to sole cropping ap-



pears an effective development pathway to enhance productivity. Specialized farming systems are likely to add much value to agriculture, contribute to food production and help to develop internationally competitive systems. In such systems all measures are fine-tuned in time and space to the specific needs of that particular crop, and high yields of crops per unit area can be obtained. Also, labour productivity can be greatly enhanced, as available technologies are geared towards this aim. Hence, much of the improvements can be obtained through the adaptation and adoption of technologies 'on the shelf'.

Sole crops or cropping systems with few specialized crops are not necessarily the only answer, and in Africa such specialization is much less appropriate than in other continents. It is unlikely that the transformation towards specialization will occur within one generation for almost 90 percent of the African farmers currently are engaged in diversified production systems. The preferred path is to exploit the advantages of diversified systems by stepwise upgrading and improving productivity. Diversified systems have developed in an environment of risk aversion where rainfed agriculture prevails, an erratic character of rainfall occurs, and (supplementary) irrigation is rare. There are good reasons to take Africa along a more diversified path of modernization than was seen in Asia in the 1970s and Europe in the 1950s.

The complex mixtures of crops and animals have to be taken as the benchmark when seeking opportunities for improvement (Landais and Lhoste, 1990). For instance, more effective use of natural resources (e.g., light and water) and added resources (e.g., fertilizer) can raise productivity of the entire system, because of optimized sharing of resources by the various crops or crop-livestock systems over time and space. It is more difficult to derive best technical means for diversified systems than for sole crop systems. Efficiency, efficacy and productivity at farming systems level may require measures and means that are not maximizing output of one specialized crop. The technologies described above require specific adaptation to make them appropriate for the various systems in Africa.

Advantages from a production ecological perspective

Some findings on synergies in intercropping systems illustrate the specific needs for developing research strategies. Crops grown in mixtures may require different characteristics than the same crops grown in sole cropping. Competition for light and nutrients, weed and disease pressure, symbioses, mechanization/harvest etc. may require adjustment through breeding



for characteristics such as leaf morphology, rooting depth, and pest and disease resistance.

Radiation use efficiency of sole (cereal) crops, for instance, is found to be equivalent to radiation use efficiency of that crop in intercropping, while the radiation use efficiency of legumes in intercropping is often higher than in sole cropping (Tsubo and Walker, 2002). Marshall and Willey (1983) found intercropping gave higher biomass (28 percent) per unit of land than the same species grown separately. Millet in intercropping intercepted 2.1 times more radiation and used it with the same efficiency, hence produced twice as much biomass. Groundnut intercepted 27 percent less radiation but used it with 47 percent higher efficiency to give the same yield. Some of these gains in total yield per unit area can be explained by the plant's flexibility in maintaining leaf area development, photosynthetic capacity and yield when subject to strong competition for light (Keating and Carberry, 1993).

Many agronomic studies have improved soil water storage by ground-cover and tillage practices and enhanced water use by combining crops. Inter-cropping is found to strongly affect the use of water by the crops. Water capture by intercrops hardly differs from water capture by sole crops, while water utilization efficiency of intercrops exceeds that by sole crops by 18-99 percent. These gains are due to various reasons: a larger portion of evapotranspiration may be captured for transpiration, due to the faster canopy closure; the dominant species with an inherently high water utilization efficiency, such as use of C₄ plants, may occupy a larger portion of both above- and below-ground resources, resulting in higher overall water utilization efficiency; finally, a favourable micro-climate of shading and vapour pressure, created for the shorter crop, may reduce transpiration (Morris and Garrity, 1993).

Overall, intercrops take up some 40 percent more phosphorus (-4 to 83 percent) and potassium (-10 to 87 percent) than sole crops. The increased uptake is more likely from the increased growth rate of the crops rather than increased availability. The larger and better functioning root systems resulting from improved growth probably explain the greater capture of non-mobile nutrients like phosphorus and molybdenum. On the other hand, species which are dominated may have reduced uptake of mobile nutrients, such as calcium, due to reduced mass flows as a result of reduced transpiration (Morris and Garrity, 1993).

Finally, intercrops are often less damaged by pest and diseases than those grown as sole crops, but effectiveness is unpredictable. Three mech-



anisms may prevent an attack, and all reduce the population growth rate of the attacker: plant associations make the intercrop combination a poor host; the combination interferes directly with the activities of the attacker; the altered environment favours natural enemies. The large variability in the impact of intercropping on pest and disease incidence and yield allows only a few generalizations (Trenbath, 1993). Certain crop combinations can for instance exacerbate a disease situation rather than reducing it. At the same time, the ability of diversified systems to suppress pest and disease incidences deserves specific attention.

Encouraging achievements in diversified systems

Diversified systems have been thoroughly studied in the past, but there has been no concerted effort to systematically exploit their potential benefits. Addressing these issues along the lines of the production ecological framework may offer new insights that will further enhance the obvious benefits of mixed intercropping (Box 4.13).

An appealing effort to this end is the integrated approach of maize-soybean cultivation in the Northern Guinea Savannah. Over the past 10 years breeders have produced the so-called dual-purpose soybean for maize

Box 4.13 Enhancing the benefits of intercropping maize and sesame

Farmers in Southeast Tanzania practice intercropping of maize with sesame. Maize is the more important crop as it secures the basic food requirements of the household. The main benefit of adding sesame to a maize crop is the possibility to generate cash shortly after harvest, when maize prices are still low. Mono-cropping of sesame is not considered a good option because of the associated risk of complete crop failure due to seedling mortality resulting from water logging, snails or sesame flea beetle. Maize and sesame are partially complementary in resource use and are hence good companion crops. Sesame is often inter-seeded two weeks after maize sowing to avoid unacceptable levels of reduction in maize production due to competition. Mkamilo (2004) showed that one of the reasons for the lack of improvement of this system in recent years is due to the fact that research efforts have mainly fo-

cused on sole cropping systems, despite the fact that 90 percent of the farmers grow these as intercrops. Breeding efforts for improved sesame varieties for instance have concentrated on yield, seed colour and oil content. The resulting improved sesame varieties were not very well suited to intercropping due to their inadequate competitiveness. Furthermore, farmers reported that the improved varieties mature during the rainy period, seeds are not readily available and are too expensive. Spatial arrangement is another concern. Research suggests one maize plant per hill, whereas farmers use two or three plants per planting hill. Particularly in intercropping systems, this last option was found superior as it enabled a better production of sesame, which was not at the cost of maize. For sesame, which is often introduced through broadcast sowing, it was shown that row seeding was the best option, as it puts less pressure

on maize. This example illustrates that a better tuning between research efforts and farmers' practices offers good scope for improvement of the performance of the system. Re-investing some of these gains back in the system seems an attractive option to trigger further development, as inputs as small as 45 kilograms of nitrogen per hectare were able to triple the yield of maize. Research is further required to close the gap between farmers' perceptions and desires, and systems performance. Farmers perceive intercropping to be less labourious, while labour requirement is in fact 42 percent higher per hectare than in sole cropping. The risks of crop failure in itself is not likely to differ between sole and intercropped sesame, and intercropping does not maintain soil fertility as is believed by the farmers.



Box 4.14 The evolution of crop-livestock systems in West Africa

Sedentary crop farming and transhumant livestock keeping live in cohabitation in the Sahelian countries of West Africa. Herds move in response to rainfall, availability of water and grazing, and the presence or absence of animal diseases. Crop growers offer crop residues for grazing by herds of herdsmen, who in turn leave their large herds on the harvested fields to provide the growers with manure (*contrat de fumure*). Also, there is exchange of cereals and milk. Nomadic herdsmen only settle and start cropping when their herd becomes too small to earn them a living – for instance, after massive animal mortality because of droughts or contagious diseases. Mixed farming and settlement, to these herdsmen, are therefore viewed as options.

This system of cohabitation is dramatically disrupted when arable farmers increase their investments in animal production. With their own livestock, these farmers no longer need manure from others and reserve their crop residues for their own animals. As the prosperity of the crop-livestock farmer grows, the number of animals increases, putting a claim on communal land resources that were formerly at the disposal of nomadic herdsmen. These developments clearly reduce the mobility of the herdsmen, deprive them of appropriate feed resources and may well impoverish them. With traditionally no land rights, herdsmen cannot easily settle, leaving little alternative for surviving the collapse of the transhumant livestock system. And even if they do settle, they must reduce the size of their herds because sedentary animal production in the form of ranching allows for much smaller numbers of livestock per hectare than do mobile systems (Van Keulen and Breman, 1990). Once in the spiralling poverty trap, it is difficult for formerly mobile livestock owners to find a way towards sedentary productive and sustainable animal production. This situation becomes worse with increasing population and demand for food. Given the low carrying capacity of the systems, the use of external inputs becomes inevitable (Slingerland, 2000).

cropping systems. They developed soybean varieties that produce a higher biomass in addition to good grain yields, fixing higher amounts of nitrogen. The soybean lines now available can produce about 2.5 tonnes of grains and 2.5-3 tonnes of forage per hectare, and there is every indication that further progress can be made. Farmers are starting to reap the benefits from maize-soybean rotations that systematically address the various aspects of production ecology.

A successful combination of intercropping is maize with pigeonpea or cowpea (promising drought-tolerant legumes that thrive on residual moisture). Both legumes can be successfully cultivated with maize, without significant compromise on yield. While both crops are sown simultaneously, the legumes start to grow only after the maize is harvested. Research in Malawi shows that pigeonpea and maize can grow sequentially in the same row, rather than in separate rows. The combination of legumes with cereals also shows increased fertilizer-nitrogen use efficiency (Mapfumo and Giller, 2001).

Refocusing breeding strategies may even lead to a complete change in farming systems. During the 1970s and 1980s, cowpea breeders sought high-yielding grain varieties. This strategy did not succeed as farmers rejected the new cultivars, due to severe attacks from various pests. The past decade has seen development of dual-purpose cowpeas, producing higher amounts of both grain and fodder. These varieties have affected agricultural intensification through crop-livestock integration in the dry savanna regions of West and Central Africa. Cowpea fodder as a supplemental feed increases animal weight during the dry season, with up to 50 kilograms of extra meat per annum from animals in some instances. Over 300 kilograms per hectare more cereal grain can be obtained as a result of improved soil fertility gained directly from the cowpea and from more and better quality of manure from the animals. The better-fed ruminants also give more milk and provide stronger traction, resulting in more and timely land preparation and better crop yields (Brader, 2002).

Box 4.14 illustrates that while the introduction of new technologies may be beneficial to some groups, it may unintentionally adversely affect others (see also Bernus et Pouillon, 1990).

Farming systems

In the above sections, emphasis was placed on productivity increase at the field level, in both specialized systems and diversified cropping. Farms in many African regions are complex units that combine their activities over time and space to maximize food security and provide for other needs



(Lhoste and Richard, 1993; Rabot, 1990; Sissoke, 1998). Opportunities for off-farm earnings also strongly influence the livelihoods of farming families. Optimization of natural resources management also needs addressing at the spatial scale, and is also influenced by off-farm activities. The adoption rate of many technology options derived from past research has been disappointing, possibly because the technologies are assessed at the crop or livestock activity level only, and this may not match the complex and multiple goals of a farm household.

In general, activities are organized such that a concentration of soil fertility occurs nearer to the farm house, indicating priority decisions made by the farmers. This phenomenon is well known and has been extensively described in the past (Prudencio, 1993; Ruthenberg, 1980). Little is however known about the way these gradients affect resource use efficiency and the way that management reinforces rather than decreases the gradient. Box 4.15 describes one attempt to better understand nutrient flows at the farm and village level. Recent work tries to explore farm-scale dynamics in terms of trade-offs at farm scale between spatial allocation of resources and temporal trade-offs between short-term yields and long-term sustainability (Giller, 2002; Tittonell, 2003).

Practical tools for NUTMON farm analysis comprise a toolbox, consisting of questionnaires, data entry and data analysis facilities, and facilities to present the results of the analysis in a way understandable for farmers (Vlaming et al., 2001). The NUTMON approach is helping research and development projects to address soil fertility management in situations of both nutrient depletion and nutrient accumulation. Currently the NUTMON Toolbox is being applied in Burkina Faso, China, Ethiopia, Ghana, Indonesia, Kenya, Mali, Thailand, Uganda and Vietnam (Van Den Bosch et al., 2001).

Most African crop and animal production is practiced under low-input agricultural systems, often because of low accessibility to external inputs, low economic returns from inputs and market risks. Many have tried to increase the productivity of these systems with or without limited external inputs. The chances for substantial improvement with low external inputs are very low, and it would be unwise to promote such low external input systems. The niche markets for some organic products in the Western world may be profitable for a limited group of farmers to generate income, but their potential contribution to increased food security is very limited.

In search of increased productivity in sorghum, Ouédraogo and colleagues (2001) applied up to 10 tonnes of compost in their experimental fields. Sorghum yields tripled compared to zero application rates – up to

Nutrient monitoring at farm level (NUTMON)

Box 4.15

The lack of nutrients – organic and mineral – and low soil fertility is a major constraint to African food supply, resulting in soil nutrient depletion with continuous cultivation. Complex African farming systems require integrated nutrient management practices to replenish soil nutrients at farm level. It requires a combination of chemical fertilizer and organic resources, reuse of the farm's limited plant nutrients, decrease in nutrients lost through leaching and volatilization, and increased supply of nutrients through biological nitrogen fixation. NUTMON is one of the many methodologies for farmers and researchers to jointly analyze the environmental and financial sustainability of diversified farming systems. Soil nutrient stocks and flows are quantified for each individual activity within the farm, unravelling the complex nature of the systems. This is combined with an economic analysis of the farm. Participatory techniques such as resource flow mapping, matrix ranking and trend analysis are used to obtain the farmers perspective. The resulting transparent picture of the farm clarifies whether to improve existing technologies or design new ones to enhance soil fertility management and increase the financial performance of the farm (Smaling and Fresco, 1993; Smaling et al., 1996).



10 tonnes per hectare. Farmers were aware of the role of compost in sustaining yield and improving soil quality. However, the lack of equipment and animals to generate enough organic material for making compost, uncertain land tenure and the intensive labour required for making compost appear to be major constraints for the adoption of compost technology. Increasing phosphorus levels in the soil and the contribution of N_2 -fixing species in the cropping systems would contribute to crop yield increase when large volumes of compost are not available.

Conclusions

The availability of technology options and the experience with their application in some African farming systems is encouraging. There are ample opportunities to bridge yield gaps, thereby increasing productivity and halt the unsustainability spiral. To do this requires systematic fine-tuning of the technology options to improve adoption. There are many examples of successful productivity-enhancing innovations that have been documented. The challenge is to scale them up and develop new options for the future. The production ecological approach can effectively support the search for location specific solutions through its ability to unravel constraints, opportunities and synergies.

There have been many success stories of productivity increases in irrigated and commercial systems practicing sole cropping in Africa. These findings are in line with the global experience of increased specialization, implying to some that the transition from diversified systems to sole cropping is a promising development pathway to enhance productivity. Diversified farming systems on the other hand have good potential to ensure food security, both in terms of increased production and productivity and in terms of income generation. Up to 90 percent of African farmers are engaged in smallholder diversified farming systems in order to ensure their livelihoods in poorly endowed biophysical and socio-economic environments.

Smallholder farmers diversify their systems for various reasons, including spreading climate and market risks; smoothing seasonal labour peaks; exploiting crop synergies (e.g., legumes and cereals, beneficial pest and diseases) and increasing land productivity. Hence market-led productivity improvement can impact on many commodities in smallholder farming systems and not require a conscious and deliberate move from mixtures to single commodities in order for them to adopt and benefit from new technology options. Indeed mixed systems should not be equated with subsis-



tence orientation. Many mixed smallholders in Africa have some marketable surpluses of the various commodities they grow. Complete specialization is not required to have market-led productivity improvements. To the extent potential or attainable productivity improvement in particular commodities in mixed systems outdoes others, so one might expect more specialization in those commodities to occur over time (i.e., they might represent a larger proportion of cropland). However, for the reasons mentioned above, there will remain incentives to have a mixed farm orientation, even including intercropping the species whose productivity has improved the most compared to others, where synergies are possible. It is not a foregone conclusion that such increased specialization will imply a move to more sole cropping at the expense of intercropping.

The transformation of smallholder diversified systems into more specialized systems may not be expected to occur within one generation; an evolutionary increase in productivity for the majority of the farmers is more likely, with many ‘rainbow evolutions’ across the many farming systems rather than one Green Revolution, as in Asia. This development pathway can meet local food and income needs while fulfilling social and cultural desires. In addition, diversified systems offer favourable options for minimizing adverse environmental consequences.

The review of mixed systems suggests promising options for productivity increases. Generally much is known about the management of soil- and rain-water in mixed systems. Fair knowledge is available on the utilization of nutrients by crop combinations. There is also general consensus that pest and disease pressures are likely to be less severe. However, there is a lack of systematic insight of all the facets of crop and animal production in complex diversified systems. The review shows that specific genetic characteristics may be required for mixtures. Little emphasis has been given in breeding programs to these issues. The insights on water and nutrient management from agronomic research are not yet fully exploited. Interesting synergies may arise when looking for interactions with other measures such as crop characteristics. Scant attention has been given to pest and disease ecology. A recent model analysis by Skelsey and colleagues (in preparation) of the impact of crop combinations on disease dissemination shows promising options and will improve the systematic search for crop combinations that minimize disease infestations. Also little emphasis has been given to the development of machines equipped to handle mixed cropping systems. Lacking the option to introduce appropriate mechanization options into diversified farming systems will limit the increases in



land and labour productivity to much lower levels than what might be technically feasible. Failing to address the increase in labour productivity has been shown to hamper adoption of technologies (e.g. Brader 2002). Labour productivity over the past four decades has not increased or even decreased in diversified systems. Enhancing labour productivity therefore requires special attention.

A closer look at current diversified systems and attempts to improve their productivity through low external input use reveals that this approach has limitations. However, incorporation of advanced technological solutions into participatory technology development with indigenous technology options can lead to co-innovations that hold large potentials and benefits for all parties.

These systems ensure the livelihoods of hundreds of millions of African farmers, although their produce rarely finds its way to world markets. To ensure the future international competitiveness of African smallholders, investments must be made in public goods, including science and technology that will help African farmers to compete effectively. In this process, objectives other than economic prosperity, such as enhancing social cohesion and ensuring livelihoods for the poorest farmers, should also be valued.

This review of agricultural production systems in Africa provides an overview of constraints to and opportunities for enhancing productivity. While currently available technology options can enhance productivity with or without specific adaptation for more specialized commercial systems, additional strategic, applied and adaptive research is urgently needed to advance the productivity of the more complex diversified smallholder farming systems. Six major programs are needed to ensure development and adaptation of technology options to the great variety of production systems in Africa in general, and to the identified four priority continental farming systems more specifically:

- An integrated nutrient and soil fertility program;
- A program of farmers' field schools for integrated pest, disease and weed management;
- A program for small-scale supplementary irrigation at specific places.
- Specific attention to genetic improvement, making use of biotechnology, including GMOS;
- A mechanization program for smallholders to enhance labour productivity; and
- An information and communications technology program.



These programs need to be both generic and specific: generic when concepts, methodologies and approaches are discussed and implemented; specific when the farming systems are considered in more detail.

Recommendations

- ▶ Adopt a market-led productivity improvement strategy
- ▶ Adopt a production ecological approach with a primary focus on identified continental priority farming systems
- ▶ Pursue a strategy of integrated sustainable intensification
- ▶ Bridge the genetic divide
- ▶ Recognize the potential of rainfed agriculture and accord it priority
- ▶ Reduce land degradation and replenish soil fertility
- ▶ Explore higher-scale integrated catchment strategies for natural resource management
- ▶ Promote the conservation, sustainable and equitable use of biodiversity
- ▶ Enhance use of mechanical energy and power
- ▶ Embrace information and communication technology at all levels
- ▶ Improve the coping strategies of farmers in response to environmental variability and climate change



References

- Abassa, K. P. 1995. Improving food security in Africa: The ignored contribution of livestock. Joint ECA/FAO agricultural division monograph No. 14. United Nations Economic Commission of Africa and Food and Agriculture Organization (UNECA/FAO). Addis Ababa.
- Adda, C., C. Borgemeister, A. Biliwa, W. G. Meikle, R. H. Markham, and H. M. Poehling. 2002. Integrated pest management in post-harvest maize: A case study from the Republic of Togo (West Africa). *Agriculture, Ecosystems and Environment*, 93: 305-321.
- Agyemang, K. 2004. Towards sustainable food security in Africa: Contribution from an ignored source – livestock agriculture. A position paper submitted to the InterAcademy Council Study on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in Africa, February 2003. Accessible at <www.interacademycouncil.net>
- Ahlawat, I. P. S., and D. S. Rana. 1998. Agro-techniques. In: Yadav, R. L., P. Singh, R. Prasad, and I. P. S. Ahlawat. Fifty years of agronomic research in India. Indian Society of Agronomy, New Delhi.
- Ahmed, M.M., and J. H. Sanders. 1998. Shifting from extensive to intensive agricultural systems: A case study in the Sudan. *Agricultural Systems*, 58: 253-268.
- Ahmed, M. M., J. H. Sanders, and W. T. Nell. 2000. New sorghum and millet cultivar introduction in Sub-Saharan Africa: Impacts and research agenda. *Agricultural Systems*, 64: 55-65.
- Ait Kadi, M. 2004. From water scarcity to water security in North Africa. In: Besri, M. (Ed.) Science and technology strategies for improving agricultural productivity and food security in North Africa: Summary, conclusions and recommendations. Rabat: IAV Hassan II/AARINENA/IAC. Accessible at <www.interacademycouncil.net>
- Asafu-Agyei. 1994. Managing cassava in a triple cropping system involving maize/cassava/cowpea. In: Akoroda, M. O. (Ed.) Root crops for food security in Africa. Proceedings of the 5th triennial symposium of the International Society for Tropical Root Crops – Africa Branch, Kampala, Uganda, 22-28 November 1992.
- Bashan, Y. 1998. Inoculants of plant growth promoting bacteria for use in agriculture. *Biotechnology Advances*, 16: 729-770.
- Bationo, A., F. Lompo, and S. Koala. 1998. Research on nutrient flows and balances in west Africa: State-of-the-art. *Agriculture, Ecosystems and Environment*, 71: 19-35.
- Bernus, E. and F. Pouillon. 1990. Sociétés pastorales et développement. *Cahiers des Sciences Humaines*, 26: 255-266
- Besri, M. (Ed) 2004. Science and technology strategies for improving agricultural productivity and food security in North Africa-Summary, Conclusions and Recommendations. Proceedings of the North Africa Workshop. Hassan II Institute of Agronomy and Veterinary Medicine (IAV Hassan II), Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA), InterAcademy Council (IAC), Rabbat, Morocco: 3-5 February 2003. Accessible at <www.interacademycouncil.net>
- Bindraban, P. S., A. (Jan) Verhagen, P. W. J. Uithol, and P. Henstra. 1999. A land quality indicator for sustainable land management: The yield gap. Report no. 106. Research Institute for Agrobiological and Soil Fertility (AB-DLO) and World Bank. Wageningen, The Netherlands.
- Bindraban, P.S., J. J. Stoorvogel, D. M. Jansen, J. Vlaming, and J. J. R. Groot. 2000. Land quality indicators for sustainable land management: Proposed method for yield gap and soil nutrient balance. *Agriculture, Ecosystems and the Environment*, 81: 103-112.
- Boelee, E. 2000. Irrigation ecology of schistosomiasis: Environmental control options in Morocco. PhD thesis January 2000.



- Brader, L. 2002. A study about the causes for low adoption rates of agricultural research results in West and Central Africa: Possible solutions leading to greater future impacts. SDR/ISC: IAR/02/22. ISC working document. Consultative Group on International Agricultural Research (CGIAR) and Food and Agriculture Organization (FAO). Rome.
- Breman, H. 1990. Integrated crops and livestock in southern Mali: Rural development or environmental degradation? In: Rabbinge, R., J. Goudriaan, H. van Keulen, F. W. T. Penning de Vries, and H. H. van Laar. (Eds.) *Theoretical production ecology: Reflections and prospects*. Simulation Monographs 34. Wageningen, The Netherlands: Pudoc Scientific Publishers.
- Breman, H. 1995. Sustainable agriculture in the Sahel? (Integrated perennials and fertilizers). In: Bouma, J., A. Kuyvenhoven, B. A. M. Bouman, J. C. Luyten, and H. G. Zandstra. (Eds.) *Eco-regional approaches for sustainable land use and food production: Systems approaches for sustainable agricultural development*. Dordrecht, The Netherlands: Kluwer Academic Publishers.
- Breman, H., Groot, J.J.R. and van Keulen, H. (2001). Resource limitations in Sahelian agriculture. *Global Environmental Change*, 11: 59-68.
- Brouwer, J., and J. Mark Powell. 1998. Increasing nutrient use efficiency in west African agriculture: The impact of micro-topography on nutrient leaching from cattle and sheep manure. *Agriculture, Ecosystems, and Environment*, 71: 229-239.
- Bruinsma, D. 1996. Review of food processing practices and opportunities in Africa: Cereals, root and tuber crops. Technical Centre for Agricultural and Rural Cooperation (CTA). Wageningen, The Netherlands.
- Brummett, R. E., and R. P. Noble. 1995. Aquaculture for African smallholders. ICARM technical report 46. The International Center for Living Aquatic Resources Management. Manila, the Philippines.
- Brummett, R. E., and M. J. Williams. 2000. The evolution of aquaculture in African rural and economic development. *Ecological Economics*, 33: 193-203.
- CGIAR (Consultative Group on International Agricultural Research). 2002. Biofortified crops and improved human nutrition. A challenge program proposal of an international consortium of collaborative partners. September 2002. <www.cgiar.org/pdf/biofortification.pdf>
- CIMMYT (International Maize and Wheat Improvement Center). 2002. Abstract: QPM development and dissemination – The success story in Ghana. <www.cimmyt.cgiar.org/research/maize/qpm2002/trainingcourse/amt_hq_2002b/casestudies/abstract.htm>
- CIMMYT. 2003. Striga weed control with herbicide-coated maize seed. <www.cimmyt.cgiar.org/research/maize/results/striga/control.htm>
- Danish Journal of Geography. 1999. Special issue No. 2, SEREIN - Environmental research in the Sahel. The Royal Danish Geographical Society Publications. Copenhagen, Denmark.
- DeVries, J., and G. Toenniessen. 2001. *Securing the harvest: Biotechnology, breeding and seed systems for African crops*. The Rockefeller Foundation. New York.
- De Wit, C. T. 1992. Resource use efficiency in agriculture. *Agricultural Systems*, 40: 125-151.
- Dobereiner, J. 1994. Biotechnologies for the development of sustainable agriculture in the tropics. In: V. Ravichandran and R.R. Daniel. (Eds.) *The role of science in food production in Africa*. Committee on Science and Technology in Developing Countries Incorporating International Biosciences and other Scientific Networks (COSTED-IBN). Madras, India.
- Dobbelaere, S., A. Croonenborghs, A. Thys, D. Ptacek, J. Vanderleyden, P. Dutto, C. Labandera-Gonzalez, J. Caballero-Mellado, J. F. Aguirre, Y. Kapulnik, S. Brener, S. Burdman, D. Kadouri, S. Sarig, and Y. Okon. 2001. Response of agronomically important crops to inoculation with *Azospirillum*. *Australian Journal of Plant Physiology* 28: 871-879.



- El Mourid, M., A. Belaid, and H. Halila. 2004. Agricultural development and food security in North Africa: Constraints and solutions. Northern Africa Workshop of the InterAcademy Council. Rabat, Morocco. Accessible at <www.interacademycouncil.net>
- Evenson, R. E., and D. Gollin. 2001. The green revolution at the end of the twentieth century. Paper prepared for TAC's standing panel on impact assessment. Technical Advisory Committee Secretariat, Food and Agriculture Organization. Rome.
- Fan, S., P. Hazell, and T. Haque. 2000a. Targeting public investments by agroecological zone to achieve growth and poverty alleviation goals in rural India. *Food Policy*, 25(4): 411-428.
- Fan, S., P. Hazell, and S. Thorat. 2000b. Government spending, growth and poverty in rural India. *American Journal of Agricultural Economics*, 82(4): 1038-1051.
- FAO (Food and Agriculture Organization). 1999. Expert consultation on bridging the rice yield gap in the Asia-Pacific region. Bangkok, Thailand, 5-7 October 1999. <www.fao.org/ag/AGP/AGPC/doc/field/commrice/session/54.htm#yie>
- FAO. 2003. FAOSTAT database. <faostat.fao.org>
- Fauré, G. 1994. Mécanisation et pratiques paysannes en région cotonnière au Burkina Faso. *Agriculture et Développement* 2: 3-14
- Franco, A. A., and D. N. Munns. 1982. Nodulation and growth of *Phaseolus vulgaris* L. in solution culture. *Plant and Soil*, 66(2):149-160.
- Franzel, S., R. Coe, P. Cooper, F. Place, and S. J. Scherr. 2001. Assessing the adoption potential of agroforestry practices in Sub-Saharan Africa. *Agricultural Systems*, 69: 37-62.
- Franzel, S. and S. J. Scherr. 2002. Trees on the farm: Assessing the adoption potential of agroforestry practices in Africa. Wallingford, Oxfordshire, UK; Cambridge, Mass.: CAB International, in association with the International Centre for Research in Agroforestry (ICRAF).
- French, R. J., and J. E. Schultz. 1984. Water use efficiency of wheat in a Mediterranean-type environment. I. The relation between yield, water use and climate. *Australian Journal of Agricultural Research*, 35: 743-764.
- Friesen, D., and J. Gressel. 2002. Biotechnology developments Africa. Picasso Headline, Cape Town, South Africa.
- Gandah, M., A. Stein, J. Brouwer, and J. Bouma. 2000. Dynamics of spatial variability of millet growth and yields at three sites in Niger, West Africa, and implications for precision agriculture research. *Agricultural Systems*, 63: 123-140.
- Garg, A. K., J. K. Kim, T. G. Owens, A. P. Ranwala, Y. D. Choi, L. V. Kochian, and R. J. Wu. 2002. Trehalose accumulation in rice plants confers high tolerance levels to different abiotic stresses. *Proceedings of the National Academy of Sciences*, 99: 15898-15903.
- Giller, K.E. 2001. Nitrogen fixation in tropical cropping systems. Second Edition. Wallingford, Oxfordshire, UK; Cambridge, Mass.: CAB International.
- Giller, K. E. 2002. In search of the middle ground. Inaugural speech by Prof. Ken Giller, Wageningen University and Research Centre. Wageningen, The Netherlands.
- Graham, R., D. Senadhira, S. Beebe, C. Iglesias, and I. Monasterio. 1999. Breeding for micro-nutrient density in edible portions of staple food crops: conventional approaches. *Field Crops Research*, 60: 57-80.
- Haight, B. A. 1994. Report of the technical consultation on the enhancement of small water body fisheries in southern Africa, Harare, Zimbabwe, 25-29 January 1993. Food and Agriculture Organization. Harare.
- Harrison, E., J. A. Stewart, R. L. Stirrat, and J. Muir. 1994. Fish farming in Africa, what's the catch? Overseas Development Administration. London, U.K.
- Heap, R. B. 1994. Can the new biotechnology increase agricultural production in sub-Saharan Africa? In: Ravichandran, V., and R. R. Daniel. (Eds.) The role of science in food pro-



- duction in Africa. Committee on Science and Technology in Developing Countries Incorporating International Biosciences and other Scientific Networks (COSTED-IBN). Madras, India.
- Hector, A., B. Schmid, C. Beierkuhnlein, M. C. Caldeira, M. Diemer, P. G. Dimitrakopoulos, J. A. Finn, H. Freitas, P. S. Giller, J. Good, R. Harris, P. Högberg, K. Huss-Danell, J. Joshi, A. Jumpponen, C. Körner, P. W. Leadley, M. Loreau, A. Minns, C. P. H. Mulder, G. O'Donovan, S. J. Otway, J. S. Pereira, A. Prinz, D. J. Read, M. Scherer-Lorenzen, E.-D. Schulze, A.-S. D. Siamantziouras, E. M. Spehn, A. C. Terry, A. Y. Troumbis, F. I. Woodward, S. Yachi, and J. H. Lawton. 1999. Plant diversity and productivity experiments in European grasslands. *Science*, 286: 1123-1127.
- Hell, K., K.F. Cardwell, M. Setamou, and H. M. Poehling. 2000. The influence of storage practices on aflatoxin contamination in maize in four agroecological zones of Benin, West Africa. *Journal of Stored Products Research*, 36: 365-382.
- Henson, S., and R.Loader. 2001. Barriers to agricultural exports from developing countries: the role of sanitary and phytosanitary requirements. *World Development*, 29: 85-102.
- IFAD/FAO/GOJ (International Fund for Agriculture Development/Food and Agriculture Organization/Government of Japan). 1998. Agricultural implements used by women farmers in Africa. Food and Agriculture Organization. Rome.
- IFDC (An International Center for Soil Fertility and Agriculture Development). 2003. <www.ifdc.org>
- IPED (International Panel of Experts on Desertification). 1994. Biological diversity in drylands of the world. International Panel of Experts – Subgroup on Biodiversity. INCD (United Nations Intergovernmental Negotiating Committee on Desertification).
- Jagtap, S. S., and A. K. Chan. 2000. Agrometeorological aspects of agriculture in the sub-humid and humid zones of Africa and Asia. *Agricultural and Forest Meteorology*, 103: 59-72.
- Kaboré, N. 1994. Banque agricole classique et SFD: Situation et perspectives au Burkina Faso. *Techniques Financières & développement*, 33: 29-32.
- Kapetsky, J. M. 1995. A first look at the potential contribution of warm water fish farming to food security in Africa. In: Symoens, J.J., and J.C. Micha. (Eds.) The management of integrated freshwater agro-piscicultural ecosystems in tropical areas. Technical Centre for Agricultural and Rural Cooperation. Wageningen University. The Netherlands.
- Keating, B. A., and P.S. Carberry. 1993. Resource capture and use in intercropping: Solar radiation. *Field Crops Research*, 34: 273-301.
- Ki-Munseki, L. 2004. Democratic Republic of Congo country paper. In: Omare, A., and D. Sheikh (Eds.) Study on science and technology strategies for improving agricultural productivity and food security in Africa – Abstracts of presentations and synthesis of discussions. Proceedings of the Workshop for Eastern and Central Africa. Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) – InterAcademy Council (IAC), Nairobi, Kenya: 31 January-2 February 2003. Accessible at <www.interacademycouncil.net>
- Kiome, R. 2004. Kenya country paper. In: Omare, A. and D. Sheikh (Eds.) Study on science and technology strategies for improving agricultural productivity and food security in Africa – Abstracts of presentations and synthesis of discussions. Proceedings of the Workshop for Eastern and Central Africa. Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) – InterAcademy Council (IAC), Nairobi, Kenya: 31 January-2 February 2003. Accessible at <www.interacademycouncil.net>
- Koudandé, O. D. 2000. Introgression of trypanotolerance genes. PhD thesis. Wageningen University. The Netherlands.
- Kristjansson, P. M., B. M. Swallow, G. J. Rowlands, R. L. Krushka, and P. N. de Leeuw. 1999.



- Measuring the costs of African animal trypanosomiasis: the potential benefits of control and returns to research. *Agricultural Systems*, 59: 79-98.
- Landais, E. and P. Lhoste. 1990. L'association agriculture-élevage en Afrique intertropicale: un mythe techniciste confronté aux réalités du terrain. *Cahiers des Sciences Humaines*, 26: 217-235.
- Lemons, J., R. Victor, and D. Schaffer. (Eds.) 2003. Conserving biodiversity in arid regions: Best practices in developing nations. Hingham, Massachusetts: Kluwer Academic Publications.
- Le Thiec, G. 1996. Agriculture africaine et traction animale. CIRAD, France, l'édition ORSTOM, Collection Atlas des structures agraires au sud du Sahara, No 21. Paris.
- Lhoste, P. and D. Richard. 1993. Contribution de l'élevage à la gestion de la fertilité à l'échelle du terroir. *Reseau Erosion Bulletin*, 14: 463-489.
- Li, X.Y., J. D. Gong, Q. Z. Gao, and F. R. Li. 2001. Incorporation of ridge and furrow method of rainfall harvesting with mulching for crop production under semiarid conditions. *Agricultural Water Management*, 50: 173-183.
- Lompo, F. 1993. Contribution à la valorisation des phosphates naturels de Burkina Faso: étude des effets de l'interaction phosphates naturels-matière organique. Thèse docteur-ingénieur, Université Nationale de Côte d'Ivoire.
- Lopez-Pereira, M. A., and M. L. Morris. 1994. Impacts of international maize research in the developing world, 1966-1990. Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).
- MacLennan, K. J. R. 1980. Tsetse-transmitted trypanosomiasis in relation to the rural economy in Africa: Part I. Tsetse infestation. *World Animal Review*, 36: 2-17.
- Madkour, M. A. 2004. Role of biotechnology in improving agricultural productivity and food security in north Africa: Case studies. In: Besri, M. (Ed.) Science and technology strategies for improving agricultural productivity and food security in north Africa. Rabat: IAV Hassan II / AARINENA / IAC. Accessible at <www.interacademycouncil.net>
- Maguswi, C. 1994. Aquaculture research and development in Zambia. In: Coche, A.G. (Ed.) Aquaculture development and research in sub-Saharan Africa. National Reviews. FAO, Rome.
- Mapfumo, P. and K. E. Giller. 2001. Soil fertility management strategies and practices by smallholder farmers in semi-arid areas of Zimbabwe. International Crop Research Institute for Semi-Arid Tropics/Food and Agriculture Organization (ICRISAT/FAO). Bulawayo, Zimbabwe.
- Maredia, M., D. Byerlee, and P. Pee. 1998. Impacts of food crop improvement research in Africa. Special program for African agricultural research (SPAAR) occasional papers series I. Africa Region. World Bank. Washington, DC.
- Maroco, J. P., J. S. Pereira, and M. M. Chaves. 2000. Growth, photosynthesis and water use efficiency responses of two sahelien grasses subjected to water deficits. *Journal of Arid Environment*, 45: 119-137.
- Marshall, B., and R. W. Willey. 1983. Radiation interception and growth in an intercrop of pearl millet/groundnut. *Field Crops Research*, 7: 141-160.
- McMillan, M. S., and W. Masters. 2003. An African growth trap: Production technology and the time-consistency of agricultural taxation, R&D and investment. *Review of Development Economics*, 7: 179-191.
- Mkamilo, G. S. 2004. Maize-sesame intercropping in southeast Tanzania: Farmers; practices and perceptions, and intercrop performance. PhD thesis. Wageningen University. Wageningen, The Netherlands.



- Morris, M., C. Clancy, and M. A. Lopez-Pereira. 1992. Maize research investment and impacts in developing countries. Part I of 1991-1992 CIMMYT maize facts and trends: Maize research investment and impacts in developing countries. Mexico, D.F.: International Maize and Wheat Improvement Center (CIMMYT).
- Morris, R. A. and D. P. Garrity. 1993. Resource capture and utilization in intercropping: non-nitrogen nutrients. *Field Crops Research*, 34: 319-334.
- MSSRF (M. S. Swaminathan Research Foundation). 2003. Assessment of impact of information technology on rural areas of India. Chennai, India. <www.mssrf.org/>
- Murray, M. and J. C. M. Trail. 1984. Genetic resistance to animal trypanosomiasis in Africa. *Preventive Veterinary Medicine*, 2: 541-551.
- NRC (National Research Council). 1996. Lost crops of Africa. Volume 1 – Grains. Board on Science and Technology for International Development. Washington, DC: National Academy Press.
- Ndiaye, M.K., M. E. S. Wopereis, T. Defoer, and D. Guindo. 2004. Improvement of the productivity of rice-based irrigation systems in West and Central Africa. In: Spencer, D.S.C. (Ed.) Science and technology strategies for improving agricultural productivity and food security in west and central Africa—Summary report. Proceedings of the Consultative Workshop for West and Central Africa, 10–12 February. Dakar, Senegal: CORAF / IAC. Accessible at <www.interacademycouncil.net>
- Nefzaoui, A. 2004. Science and technology strategies for the control of desertification in north Africa. Northern Africa Workshop of the InterAcademy Council. Rabat, Morocco. Accessible at <www.interacademycouncil.net>
- Noble, R. P. 1996. Wetland management in Malawi: A focal point for ecologically sound agriculture. Center for Information and Research on Low External Input and Sustainable Agriculture (ILEIA). *ILEIA Newsletter*, 12: 9-11.
- Nyirara, A. M. 1994. Technological change in indigenous root and tuber crop production systems in Sub-Saharan Africa. In: Akoroda, M. O. Root crops for food security in Africa. Proceedings of the 5th triennial symposium of the International Society for Tropical Root Crops – Africa Branch. Kampala, Uganda, 22-28 November 1992.
- Odigboh, E. U. 2002. State of agricultural mechanization in Nigeria. In: Animalu, A. O. E. (Ed.) Science today in Nigeria. Nigerian Academy of Science, Abuja.
- Omare, A., and Sheikh, D. (Eds.) 2004. Study on science and technology strategies for improving agricultural productivity and food security in Africa – Abstracts of presentations and synthesis of discussions. Proceedings of the Workshop for Eastern and Central Africa. Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) – InterAcademy Council (IAC), Nairobi, Kenya: 31 January-2 February 2003. Accessible at <www.interacademycouncil.net>
- Otsuki, T., J. S. Wilson, and M. Sewadeh. 2001. Saving two in a billion: Quantifying the trade effect of European food-safety standards on African exports. *Food Policy*, 26: 495-514.
- Ouédraogo, E., A. Mando, and N. P. Zombré. 2001. Use of compost to improve soil properties and crop productivity under low-input agricultural systems in West Africa. *Agriculture, Ecosystems, and Environment*, 84: 259-266.
- Perry, B. D., T. F. Randolph, J. J. McDermonnt, K. R. Sones, and P. K. Thornton. 2002. Investing in animal health research to alleviate poverty. Nairobi, Kenya: International Livestock Research Institute.
- Prudencio, C.F. 1993. Ring management of soils and crops in the West African semi-arid tropics: the case of the Mossi farming systems in Burkina Faso. *Agriculture, Ecosystems and Environment*, 47: 237-264.



- Rabot, C. (1990). Transfert de fertilité et gestion de terroirs. *Les cahiers de la Recherche-Développement* 25: 19-32.
- Ratti, N., S. Kumar, H. N. Verma, S. P. Gautam. 2001. Improvement in bioavailability of tricalcium phosphate to *Cymbopogon martinii* var. *motia* by rhizobacteria, AMF and *Azospirillum* inoculation. *Microbiological Research* 156:145-149.
- Raven, J. A., A. A. Franco, E. L. de Jesus, and J. Jacob-Neto. 1990. H⁺ extrusion and organic acid synthesis in N₂-fixing symbioses involving vascular plants. *New Phytology*, 114: 369-389.
- Rockström, J. 2001. Green water security for the food makers of tomorrow: windows of opportunity in drought-prone savannahs. *Water Science and Technology*, 43: 71-78.
- Rohrbach, D. 1989. The economics of smallholder maize production in Zimbabwe: Implications for food security. MSU international development paper no.11. East Lansing: Department of Agricultural Economics, Michigan State University.
- Rohrbach, D., and K. Mutiro. 1996. Formal and informal channels of sorghum and pearl millet seed supply in Zimbabwe. Paper presented at National Seed Policy Workshop, 30-31 July 1996, Harare, Zimbabwe.
- Roseboom, J., N. Beintema, S. Mitra, B. Njobe, and J. Ryan. 2004. Building impact-oriented science, research and technology development and transfer institutions. Background document IAC study on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in Africa. Accessible at <www.interacademycouncil.net>
- Rosegrant, M.W. and N. D. Perez. 1997. Water resources development in Africa: A review and synthesis of issues, potentials, and strategies for the future. Environmental and production technology division discussion paper 28. International Food Policy Research Institute. Washington, DC.
- Rueda-Puente, E.O., T. Castellanos, E. Troyo-Diéguez, J. L. D. León-Alvarez. 2004. Effect of *Klebsiella pneumoniae* and *Azospirillum halopraeferens* on the growth and development of two *Salicornia bigelovii* genotypes. *Australian Journal of Experimental Agriculture*, 44: 65-74
- Ruthenberg, H. 1980. *Farming Systems in the Tropics*. 3rd ed. Oxford, U.K.: Clarendon Press.
- Salih, S. H. 2004. Sudan country paper. In: Omare, A. and D. Sheikh. (Eds), Study on science and technology strategies for improving agricultural productivity and food security in Africa. Proceedings of the Workshop for Eastern and Central Africa, 31 January-2 February. Nairobi, Kenya: Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and InterAcademy Council (IAC). Accessible at <www.interacademycouncil.net>
- Sanchez, P. A. 2002. Soil fertility and hunger in Africa. *Science*, 295: 2019-2020.
- Shetty, S. V. R., S. K. Debrah, and C. Renard. 1995. Technology development, testing and transfer: An overview of ICRISAT's experience in semi-arid Africa. In: Kang, et al. (Eds.) *Moist savannas of Africa: Potentials and constraints for crop production*. International Institute of Tropical Agriculture and Food and Agriculture Organization (IITA and FAO). Ibadan, Nigeria, 249-265.
- Sissoko, K. 1998. *Et demain l'agriculture? Options techniques et mesures politiques pour un développement durable en Afrique subsaharienne. Cas du cercle de Koutiala en zone sud du Mali*. PhD thesis. Wageningen University, The Netherlands.
- Sisti, C. P. J., H. P. Sants, R. Kochhann, B. J. R. Alves, S. Urquiaga, and R. M. Boddey. 2003. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage



- in southern Brazil. *Soil and Tillage Research* (accepted).
- Skelsey, P, W. A. H. Rossing, G. J. T. Kessel, and W. van der Werf. (in preparation). Influence of host diversity on development of epidemics of potato late blight: an evaluation and elaboration of mixtures theory. Wageningen University and Research Centre. The Netherlands.
- Slingerland, M. A. 2000. Mixed farming: Scope and constraints in West African Savanna. PhD thesis. Wageningen University, The Netherlands.
- Smale, M. and P. Heisey. 1994. Maize research in Malawi revisited: An emerging success story? *Journal of International Development*, 6(6): 689-706.
- Smaling, E. M. A., S. M. Nandwa, H. Prestele, R. Roetter, and F. N. Muchena. 1992. Yield response of maize to fertilizers and manure under different agro-ecological conditions in Kenya. *Agriculture, Ecosystems, and Environment*, 41: 241-252.
- Smaling, E. M. A., and L.O. Fresco. 1993. A decision – support model for monitoring nutrient balances under agricultural land use (NUTMON). *Geoderma*, 60:235-256.
- Smaling, E.M.A, L.O. Fresco, and A.de Jager. 1996. Classifying, monitoring and improving soil nutrient stocks and flows in African agriculture. *Ambio*, 25: 492-496.
- Spencer, D.S.C. (Ed.) 2003. Science and technology strategies for improving agricultural productivity and food security in West and Central Africa – Summary report. Proceedings of the Consultative Workshop for West and Central Africa. CORAF – InterAcademy Council (IAC), Dakar, Senegal: 10-12 February 2003. Accessible at <www.interacademycouncil.net>
- Stomal, B. and J. Y. Weigel. 1998. Mythes et realites des aquacultures africaines. *Afrique Contemporaine*, 187: 60-76.
- Thilsted, S.H., and N. Roos. 1999. Policy issues on fisheries in relation to food and nutrition security. In: Ahmed, M., C. Delgado, S. Sverdrup-Jensen, and R. A. V. Santos. (Eds.) Fisheries policy research in developing countries: Issues, priorities and needs. ICLARM Conference Proceedings 60. International Center for Living Aquatic Resources Management. Manila, the Philippines.
- Thomson, J. 2002. Genes for Africa: Genetically modified crops in the developing world. Landsdowne, South Africa: UCT Press.
- Tilman, D. 1997. Distinguishing between the effects of species diversity and species composition. *Oikos* 80: 185.
- Tittonell, P. 2003. Soil fertility gradients in smallholder farms in western Kenya. Their origin, magnitude and importance. MSc thesis. Production Ecology. Plant production system group. Department of Plant Science. Wageningen University, Wageningen. The Netherlands.
- Trenbath, B.R. (1993). Intercropping for the management of pests and diseases. *Field Crops Research*, 34: 381-405.
- Tsubo, M. and Walker, S. (2002). A model of radiation interception and use by a maize-bean intercrop canopy. *Agricultural and Forest Meteorology*, 110: 203-215.
- UNEP/CBD/SBSTTA. 1999. Assessment of the status, trends, and options for conservation and sustainable use of terrestrial biological diversity: Dryland, mediterranean, arid, semi-arid, grassland, and savannah ecosystems. United Nations Environment Program (UNEP).
- Van den Bosch, H., D. Eaton, M. S. van Wijk, J. Vlaming, and A.de Jager. 2001. Monitoring nutrient flows and economic performance in African farming systems: The NUTMON approach and its applicability to peri-urban agriculture. In: Drechsel, P., and D. Kunze. (Eds) Waste composting for urban and peri-urban agriculture: closing the rural-urban nutrient cycle in Sub-Saharan Africa. Ghana: FAO Regional Office for Africa.
- Van der Waaij, L. 2001. Breeding for trypanotolerance in African cattle. PhD thesis. Wageningen University. The Netherlands.



- van Keulen, H., and H. Breman. 1990. Agricultural development in the West African Sahel region: a cure against land hunger? *Agricultural Ecosystems and Environment*, 32: 177-197.
- Van Straaten, P. 2002. Rocks for crops: Agrominerals of Sub-Saharan Africa. ICRAF (International Centre for Research in Agroforestry), Nairobi, Kenya.
- Vlaming, J., M.S. van den Bosch, J. van Wijk, A.de Jager, A. Bannink, and H. van Keulen. 2001. Monitoring nutrient flows and economic performance in tropical farming systems (NUTMON). Alterra Green World Research. Wageningen University and Research Centre. The Netherlands.
- Wanbugu, F. 2001. Modifying Africa – How biotechnology can benefit the poor and hungry: A case study from Kenya. Nairobi, Kenya.
- Warner, J. F., and E. Simpungwe. 2003. Stakeholder participation in South Africa: Power to the people? Paper presented at the IAHS (International Association of Hydrological Sciences) conference, Stellenbosch, South Africa, January 2003.
- Ye, Y. 1999. Historical consumption and future demand for fish and fishery products: Exploratory calculations for the years 2015/2030. FAO Fisheries Circular No. 946. FIPP/C946. Food and Agriculture Organization. Rome.



5. Building impact-oriented research, knowledge and development institutions

Introduction

Institutions are the vehicles that enable the expression of science and technology (s&t) potential, thereby contributing to the improvement of agricultural productivity and food security. They are predominantly public in Africa, with the private sector playing a minimal role up to now. The national agricultural research systems in Africa have been undergoing reforms to make them more responsive and effective. Institutional innovations designed to strengthen national agricultural research systems are being explored. There are also subregional and continental initiatives designed to economize on scarce resource and development (R&D) resources by exploiting synergies and research spillovers across similar agro-ecologies and farming systems.

In this chapter we examine the current status of agricultural R&D institutions in Africa and the trends in their evolution and impacts, including funding, and attempt to diagnose the challenges that they face. We conclude with an assessment of desirable future strategies and priorities.

Institutional arrangements

African countries today typically have a complex array of institutions responsible for the planning, funding and conduct of agricultural research and the dissemination of technology options arising from it. These include national agricultural research institutions (NARIS), universities, international agricultural research centres (IARCS) and extension services, which historically have been publicly funded. In addition there is the private sector, farmer organizations, nongovernmental organizations (NGOs) and community-based organizations (CBOs) that are predominantly funded from private sources. The national agricultural research system (NARS) embodies this array, although the elements largely act independently of each other with a minimum of coordination.



National

About half of the 54 countries in Africa have agricultural research systems that employ fewer than 100 full-time equivalent (FTE) researchers (Table 5.1). Egypt has by far the biggest system, employing close to 6,700 FTE researchers. This is some 36 percent of Africa's national agricultural research capacity (Figure 5.1a). Nigeria and South Africa represent the second league of research systems, each employing more than 1,000 FTE researchers. In 39 of the 54 countries the NARI is the dominant agricultural research entity and represents typically more than half of the NARS capacity. Initially, the adoption of a NARI model led to a consolidation of research capacity; but, subsequently, this again became diffused. Research capacity at universities is in most countries small and fragmented, but has tended to grow slightly faster than the research capacity of non-academic agencies. Moreover, the share of universities in total agricultural research capacity increases with the size of the NARS. Among African national agricultural research systems with less than 100 FTE researchers, universities contain 12 percent of the research capacity, while among African national agricultural research systems with 500-1,500 FTE researchers the share is 22 percent. Nigeria has the highest percentage of FTE agricultural researchers (38 percent) located at universities.

Table 5.1 Classification of African countries by the size of their national agricultural research system

Number of full-time equivalent researchers	
Less than 25	Comoros, Equatorial Guinea, Guinea Bissau, Liberia, Sao Tome & Principe, Seychelles, Swaziland
25-100	Angola, Benin, Botswana, Burundi, Cape Verde, Central African Republic, Chad, Congo Republic
101-250	Burkina Faso, Congo Democratic Republic, Cote d'Ivoire, Guinea, Madagascar, Malawi, Mauritius, Niger, Senegal, Uganda, Zambia, Eritrea, Gabon, Gambia, Lesotho, Mauritania, Mozambique, Namibia, Reunion, Rwanda, Sierra Leone, Somalia, Togo
251-500	Algeria, Cameroon, Ghana, Libya, Mali, Tunisia, Zimbabwe
501-1,000	Ethiopia, Kenya, Morocco, Sudan, Tanzania
1,001-1,500	Nigeria, South Africa
Greater than 1,500	Egypt

Source: Roseboom et al. (2004).



Government research agencies represent 81 percent of total research capacity of African national agricultural research systems. Universities contribute 18 percent, with the private and non-profit sectors as the remaining 1 percent. The university contribution is comparable to the figure of 12 percent for Organization for Economic Co-operation and Development (OECD) countries, excluding research and development in food processing, agricultural machinery and agrochemicals. Slowly but steadily over the last 20 years universities are becoming a more important component of agricultural research in Africa (Michelsen et al., 2003; Beintema et al., 1998). Box 5.1 details the evolution of African universities.

The proliferation of universities and students in Africa and stagnant funding since the 1960s has resulted in declining standards, facilities and performance. There is a need to rationalize the university system and identify those which will be regional centres of excellence for research and postgraduate training and those that will focus on undergraduate teaching. Universities could benefit from more autonomy and less centralized control. Information and communications technology provides an opportunity for virtual universities. The World Bank policy of not lending or making grants for higher education should be abolished in recognition of the special needs in Africa.

Non-profit private agricultural research is primarily on important export crops where commodity cesses are used to fund the research, the research agenda being increasingly set by farmers who produce the mostly non-food commodities concerned. These agencies date from colonial times and

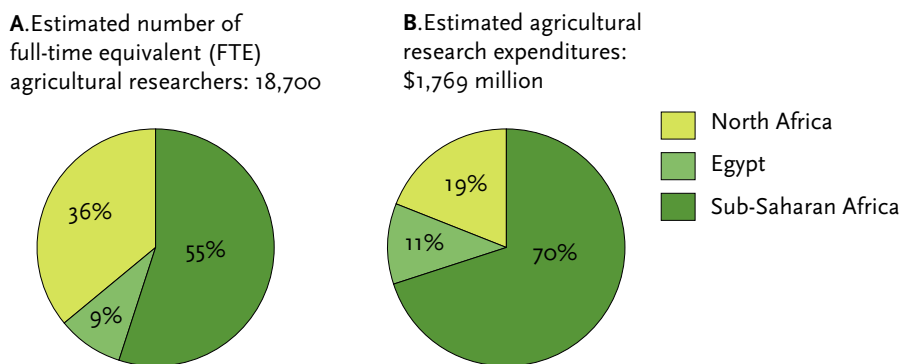


Figure 5.1A-B Distribution of African agricultural research capacity by FTE researchers and R&D expenditures.

Note: Based on latest observation available between 1990 and 2000. For a number of countries the expenditure data have been constructed by multiplying the number of FTE researchers with an average expenditure-per-researcher figure.

Source: Roseboom et al. (2004)



Box 5.1 The evolution of African universities

University developments in Sub-Saharan Africa can be roughly divided into three phases: a vigorous expansion phase from independence in 1960 to approximately 1980 when the number and sizes of universities expanded rapidly, with large increases in the numbers of undergraduates produced. Between 1960 and 1996, the number of universities in Sub-Saharan Africa increased from less than 20, to nearly 160. Student numbers grew by 8 percent per year, from 119,000 to almost 2 million over the same period. Funding of higher education generally matched the expanded number of universities and students during the 1960 and 1970s but then fell well below growth in numbers of students since the early 1980s. The expansion phase of the 1960s and 1970s was followed by a retrenchment phase in the 1980s and renewal phase in the early 1990s.

Two strategies employed during the expansion phase are of particular interest. The first was the introduction of the U.S. Land Grant University model in the 1960s and 1970s with its triple mission of integrated research, extension and teaching. A number of U.S. universities, with U.S. Agency for International Development (USAID) support, helped set up a number of new universities in Sub-Saharan Africa that embodied some of the

Land Grant ideas. But the research and extension missions of the Land Grant model, generally introduced under Ministries of Higher Education, came into conflict with entrenched research and extension departments in Ministries of Agriculture. By the 1980s, most of the Land Grant type universities were converted into all-purpose universities with emphasis on undergraduate teaching. The Land Grant model was not introduced into Northern Africa.

Because of the failure of the Land Grant model in Sub-Saharan Africa, delegations from Nigeria and Tanzania visited India in the early 1980s to study India's innovative State Agricultural University (SAU) model. In the SAU model, university vice chancellors report to the Ministry of Agriculture rather than the Ministry of Higher Education in order to increase the connectivity between research, extension and agricultural higher education. Subsequently, Nigeria set up three federal universities of agriculture based on the SAU model, but they too experienced difficulties. After a Tanzanian delegation visited India, the Sokoine University of Agriculture in Tanzania was established in 1984 by upgrading the Faculty of Agriculture at Morogoro into a University with emphasis on agriculture, forestry and veterinary medicine. But the Indian SAU model also

floundered in Africa. The failure of both models suggests that imported institutional models must be more closely adapted to African institutional, financial and political realities if they hope to succeed. Indeed instead of further experimentation with imported university models, perhaps Africa, in common with universities everywhere, needs stronger inter-institutional linkages as detailed elsewhere in this chapter and in the first InterAcademy Council report *Inventing a better future* (IAC, 2004).

A second large university experiment was the 20-year University Development Program financed by the Rockefeller Foundation from 1963 until 1983. Three African universities (Nairobi, Ibadan and Kinshasa) participated in this 12-country global experiment with the aim of helping universities become more effective in addressing concrete development problems. The initiative was brought to an early close, however, because of mixed results and unexpected political difficulties in a number of countries, including the Congo and Nigeria. A study of this experience highlighted the substantial amount of time needed to develop strong postgraduate programs, adequate infrastructure, a motivated and well-paid academic staff, and adequate indigenous financial support to ensure sustainability.

are usually well managed when producer control is strong (Kangasniemi, 2002). They now extend their reach to provide some producer-funded extension. Historically extension in Africa was always publicly funded, especially for food crops.

In 44 countries the Ministry of Agriculture is primarily responsible for agricultural research. The Ministry of Science is the responsible agency in only 10 of the countries and all but two of these 10 are francophone. Within these Ministries there can be several separate departments responsible for individual components of the national agricultural research system, making coordination difficult. Competitive research funding is gradually being recognized as a means to enhance institutional cooperation and collaboration in this complex environment. To improve stakeholder participation in governance of publicly funded agricultural research, representa-



tives of farmer organizations and agricultural industries are being appointed to boards of national agricultural research institutions. However civil servants and political appointees, not technical and scientific personnel or agricultural producers, still dominate such boards.

Regional

Since the mid-1980s there has been an increasing investment in subregional organizations designed to improve the coordination of agricultural research among the national agricultural research systems, share information, build capacity and economize on research resources. The first was the Southern African Centre for Cooperation in Agricultural Research (SACCAR) established in 1984. The Association of Agricultural Research Institutes in the Near East and North Africa (AARINENA) followed this in 1985. The West and Central African Council for Agricultural Research and Development (WECARD/CORAF) was created in 1987. The most recent and arguably most effective regional body was the Association for Strengthening Agricultural Research in Central and Eastern Africa (ASARECA), formed in 1993.

Research networks, originally initiated by the international agricultural research centres prior to the formation of the subregional organizations, are now key to the functioning of subregional organizations. These were often started on a commodity basis but more recently natural resource management networks have been established. Networks are a more successful means of sharing information than efforts to jointly define and implement regional research programs on agreed regional priorities, which allow specialization by national agricultural research systems that become strong in particular fields. The intention with the latter was to achieve critical mass in high priority themes and share the results among all members, thereby making more effective use of scarce research resources to the benefit of all national agricultural research systems, especially the smaller ones (Roseboom et al., 1998).

But reaching agreement on regional priorities has been elusive and countries continue to pursue self-sufficiency in those aspects of agricultural research where they feel weakest. The dynamic intellectual property rights regime has further hampered the extent of cooperation originally envisaged. It is expected that the recent establishment of subregional competitive grant schemes for agricultural research by the European Union will further enhance regional collaboration in the ASARECA and CORAF regions. A similar facility is also available for the Southern Africa



Development Community (SADC), but its decision to rationalize and restructure the Southern African Centre for Cooperation in Agricultural Research (SACCAR) in 2002 has left a vacuum in this area and implementation seems to be delayed.

Continental

The Forum for Agricultural Research in Africa (FARA), established in 2002, arose from the Special Program for African Agricultural Research (SPAAR), which the World Bank initiated in the early 1990s. The establishment of FARA completed the chain linking African agricultural scientists to the Global Forum for Agricultural Research (GFAR). At present, FARA and the sub-regional organizations are contributing to the development of the Consultative Group on International Agricultural Research (CGIAR) Sub-Saharan Africa Challenge Program. Such a Challenge Program would not only involve CGIAR centres but also all elements of the national agricultural research systems and other potential partners both within and outside Africa, including advanced research institutions. This initiative arose following the Third System Review of the CGIAR in 1998, which examined how to collaborate more effectively as equal partners with the African national agricultural research systems. A similar initiative was launched by the CGIAR for the Central and West Asia and North Africa region in 2000.

Currently, all 16 international advanced research centres of the CGIAR have African programs. Overall they devote 48 percent of their scientific human resources to Africa. Two of the centres – the International Institute of Tropical Agriculture (IITA) and the West African Rice Development Association (WARDA) – devote 100 percent to Africa. Research staff numbers at the international advanced research centres represent less than 3 percent compared with the total FTE researchers in the national agricultural research centres of Africa. In addition to the CGIAR centres, there are other independent international advanced research centres conducting research, as well as the sizeable efforts France's Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD) and Research Institute for Development (IRD, previously ORSTOM). The latter two have almost twice the number of scientists working on Africa than do the CGIAR centres. Hence the overall contribution of international agencies comprises about 10 percent of the total agricultural research capacity in Africa. This is substantially more than in Asia and Latin America.

There is a strong sentiment among many African national agricultural research systems and some institutions in the donor community that the



16 CGIAR centres should consolidate their African programs, activities and management into two or three regional centres. Over time it is felt these centres should be African owned and governed, instead of having the degree of independence they currently have under the CGIAR governance structure. The Sub-Saharan Africa Challenge Program is not viewed by the national agricultural research systems and donors as a substitute for fundamental changes in the way the CGIAR centres operate in Africa. While the loose conglomerate structure of the CGIAR worked well for much of the 1970s and 1980s, it now may be a disadvantage. However the Study Panel believes the CGIAR centres continue to be an essential element in achieving agricultural productivity gains and improved food security in Africa and that they must retain their international character.

At the international level, donors are increasingly unwilling to provide core support for the international advanced research centres based on system research priorities recommended by the CGIAR interim Science Council (previously the Technical Advisory Committee). Instead they have restricted their funding to their own thematic and geographic priorities, thereby eroding the *raison d'être* of the CGIAR. There is no effective mechanism that checks whether the overall research agenda that evolves is consistent with agreed priorities of the system, even though in principle that is one of the roles of the Science Council. Unrestricted budget allocations to the CGIAR in support of the agreed agenda dropped from 69 percent in 1991 to 43 percent in 2001. There are signs that this trend may intensify in the years ahead. In this climate there is a question about the viability of the whole CGIAR concept based on a system of independent international agricultural research centers. The Study Panel is concerned about this situation. It is not convinced at present that African-owned and African-governed international advanced research centres are real substitutes for the CGIAR concept of truly international agricultural research centres.

The Study Panel recommends that the international advanced research centres with headquarters in Africa, and those with programs there but headquarters elsewhere, must integrate their activities explicitly in order to respond more effectively to African priorities. This could include ceding to 2-3 African-headquartered international advanced research centres the responsibility for governance, management and oversight of the African regional programs of other international advanced research centres. At present international advanced research centres with headquarters or major subcentres in Africa host staff of other centres. This must immediately extend to full programmatic integration. The scope for full institutional integration should be explored by the CGIAR as a matter of priority.



There is evidence that integration is occurring – for example the recent decision by the International Food Policy Research Institute (IFPRI) and International Livestock Research Institute (ILRI) to appoint a joint director of their respective policy and livestock marketing programs. The recommendation of the External Program and Management Review Panel of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to move its headquarters to Africa may be a less-preferred way to achieve an enhanced institutional focus on Sub-Saharan Africa than to cede programmatic integration to existing centres with headquarters in Africa. The Study Panel is encouraged that the CGIAR is planning to conduct a review of the structure of its operations in Africa in the near future where these and other issues can be considered in a comprehensive manner.

Only strong national and international advanced research centres and universities will make a difference in African science and technology. All these institutions must have a substantial increase in their resources, without which the proposed Challenge Program for Sub-Saharan Africa will not succeed. The stakeholders in the Challenge Program recognize this and indeed see it as a mechanism for building stronger agricultural R&D institutions at all levels. The Study Panel also does not regard this Challenge Program as a substitute for strong R&D institutions. However, in its current form, it has emphasized process rather than problems, with attendant large transaction costs. Contrary to the intention, the Challenge Program for Sub-Saharan Africa might only be a zero-sum financial game at the expense of existing institutions. These concerns were conveyed to the Study Panel during the consultative workshops.

Along with the strengthening of national and regional research as recommended in this report, the Study Panel strongly urges that CGIAR centres reposition themselves with respect to their work and impact in Africa in the following manner:

- In the medium term, the current governance structures (Boards) of all the international advanced research centres should become more balanced with respect to African participation, ownership and accountability. It is proposed that national agricultural research systems play a more significant role in the selection process of the actual board members.
- The CGIAR Secretariat should facilitate NARS and subregional organizations engagement with the system as a whole, and act as custodian for reporting progress in the development of both, in recognition that they are critical stakeholders in and beneficiary of the CGIAR centres' work.
- In their impact evaluation activities, the CGIAR centres need to ensure



that governments in partner countries are considered as a critical audience, alongside the investors and scientific community.

- The communication strategy and action plan of the CGIAR must be expanded beyond the traditional donor community to include high-level policymakers in governments, private sector and knowledge institutions in developing and developed countries.

The Study Panel sees considerable merit in the cultivation of African centres of agricultural research excellence (ACARE) from existing strong national agricultural research institutes and universities. The New Partnership for Africa's Development (NEPAD) has also urged the creation of such centres. In the Study Panel's view there are important reasons why:

- There is a priority strategic research agenda that is unmet by existing institutions.
- Regional agricultural research networks under the auspices of the sub-regional organizations have been unsuccessful in coordinating the conduct of agricultural research among the national agricultural research systems to exploit synergies and comparative advantages and to economize on scarce agricultural research resources. Although they have succeeded in facilitating information sharing, individual national agricultural research systems have been reluctant to cede responsibility for priority research to other national agricultural research systems. The ACARE programs on the other hand would have a mandate to ensure this.
- Africans need to assume the responsibility for research leadership and be accountable for the resources they receive to pursue strategic research on priority themes.
- ACARES will attract Africa's best and the brightest scientists from the continent and perhaps the Diaspora, acting as a magnet to stimulate, reward, retain and perhaps even regain the 'brains.'
- ACARES will provide a focal point to mobilize additional resources for agricultural research in Africa focused on African problems.
- ACARES would allow exploitation of economies of size and research spillovers and reduce the risk of duplicated effort among often small and fragmented current programs.
- ACARES would have a responsibility to strengthen African national agricultural research systems.
- ACARES would be a visible sign that African governments affirm the strategic importance of internationally recognized African scientific institutions for improving agricultural productivity and food security.

The ACARE would have the following characteristics:



- Evolve from existing institutions rather than be created de novo; where possible such centres may operate as virtual centres of research with shared, well-focused aims.
- Be African led, owned and governed.
- Be supported in both cash and kind by African governments and the international donor community.
- Be independent research institutions.
- Have a recruitment policy (based on academic merit) that reflects the pursuit of scientific excellence.
- Have a salary structure that is competitive and does not differentiate among nationalities.
- Be able to establish headquarters agreements with African host governments that accord them the appropriate immunities and privileges to facilitate the pursuit of their regional (international) mandates.
- Operate in close collaboration and partnership with farmers, national agricultural research institutions, universities, international advanced research centres and advanced research institutions.
- During the evolution of ACARES, care should be taken to avoid the depletion of human and financial resources of existing research institutions.
- Some ACARE would have continental mandates and others regional mandates.

There are several themes of continental priority, which are currently not addressed adequately by either national agricultural research systems or international advanced research centres, that could be candidates for ACARE. They include:

- Biotechnology;
- Biodiversity and plant genetic resource gene mapping of relevant crops, and their characterization, conservation, and cataloguing;
- Fisheries and aquaculture;
- Water, conceived in an integrated approach, from its catchment to its release;
- Soil fertility, conservation and sustainability;
- Small ruminants;
- Game and wildlife;
- Policy, information and communications technology, data generation and management.

In addition, a number of eco-regional ACARE could be initiated, including:

- Semi-arid tropical rainfed agriculture;



- Pastoral systems;
- Humid/subhumid tropical systems; and
- Highland systems.

Models for the ACARE could include the African Capacity Building Foundation (ACBF), WARDA, International Centre for Insect Physiology and Ecology (ICIPE), International Trade Centre (ITC) and the Southern African Development Community (SADC) Genetic Resources Centre. Twinning arrangements of ACARES with advanced research institutions during their development could help to attain the desired critical mass and levels of expertise. The CGIAR centres could in some instances become a core element or a foundation for an ACARE, such as the case of ILRI with the recently formed African BioSciences Centre.

The Cooperative Research Centre (CRC) model in Australia could offer a useful template for the ACARE interactions with other stakeholders. This program began in 1990 to improve the effectiveness of Australia's R&D effort in six sectors, one of which was agriculture. The CRC links researchers from universities, state and federal research institutions, like Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO), and private industry to focus R&D efforts on progress toward utilization and commercialization. The close interaction between researchers and the users of research is a key feature of the CRC framework. Another feature is industry contributions to CRC education programs to produce industry-ready graduates.

ACARE will only be viable and worthwhile if they evolve at the same time as national agricultural research systems in Africa are strengthened. ACARE are perceived by the Study Panel as complements to strong national agricultural research systems and must emerge from those that have track records and critical mass. To be successful in translating their research into productivity gains in farmers' fields, ACARE must be an integral part of the proposed knowledge generation and diffusion quadrangle described later in this chapter.

The first IAC report *Inventing a better future* makes a strong case for autonomous centres of excellence in science and engineering in developing countries, whether of local, national, regional or international status: 'Centers of excellence are the key to innovation, and their importance cannot be overestimated.' The IAC report contains many examples of successful centres of excellence in science and technology and their features, which can provide valuable guidance to plan for ACARE (IAC, 2004).



Agricultural research strategies and policies

During the past 20 years in Africa, a great deal of emphasis has been placed on the development of national agricultural research strategies and priorities, which have often occurred within the context of World Bank loans. One of the CGIAR centres, the International Service for National Agricultural Research (ISNAR) has frequently been associated with the development of these strategies and priorities (Hambly and Setshwealo, 1997). In spite of this, agricultural research does not come high on the list of priorities in the Poverty Reduction Strategy Papers of African countries (Figure 5.2). Twenty-four of these papers have been reviewed by the Study Panel and it has been found that, while agriculture is seen as a key component of economic growth and poverty reduction, science and technology is mentioned as an important element in only half the cases. Only four of the 24 papers mention agricultural research as a priority for poverty reduction.

There is a need to develop coherent national and regional agricultural s&t strategies and policies. There may be a greater role for national councils of science and technology, academies of science and professional associations in this respect. A scientific advisor or chief scientist, who is responsible to the Prime Minister, is viewed by many as a necessary complement to these initiatives. Also the contributions of national agricultural research systems and subregional organizations for this process should be explored. Any R&D priority setting requires improvement, with greater accountability of all actors and stakeholder participation. There is also a need for role clarity through strengthened monitoring and evaluation capabilities and geo-referenced data and information management.

African governments see technology diffusion as being more of a constraint than technology generation. The most frequently mentioned agricultural priorities in the Poverty Reduction Strategy Papers were the improvement of rural infrastructure, development of markets, extension/advisory services, diversification out of agriculture, a special focus on women farmers, farmer training and promotion of farmer organizations. These were consistent with the priorities that emerged in the consultative workshops the Study Panel conducted in collaboration with the subregional organizations. They are also reflected in the current strategies of the subregional organizations and FARA.

The notion that technologies available 'on-the-shelf' are sufficient to solve *all* or most agricultural problems in Africa has been a factor in the continuing decline in the funding of research by governments, donors and international financial institutions since the 1980s. For example, the



World Bank funding for African agricultural research went from a peak of US\$120 million in 1991 to US\$8 million in 2002 (in 1993 dollars). That of USAID went from a peak of US\$80 million in 1982 to US\$4 million in 1999. Other sectoral priorities, such as health and education, have also emerged as funding competitors with agricultural research.

The Study Panel concurs with a short-term strategy of exploiting technologies on-the-shelf by enhancing investments in infrastructure, adaptive and participatory research with farmers by improved policies, market access and information. However, keeping the technology pipeline flowing requires a renewed emphasis on long-term strategic and applied research in, and for, Africa by Africans. This type of research has much longer lead and lag times than adaptive research. The lack of priority accorded to agricultural research in the Poverty Reduction Strategy Papers does not augur well for this to happen.

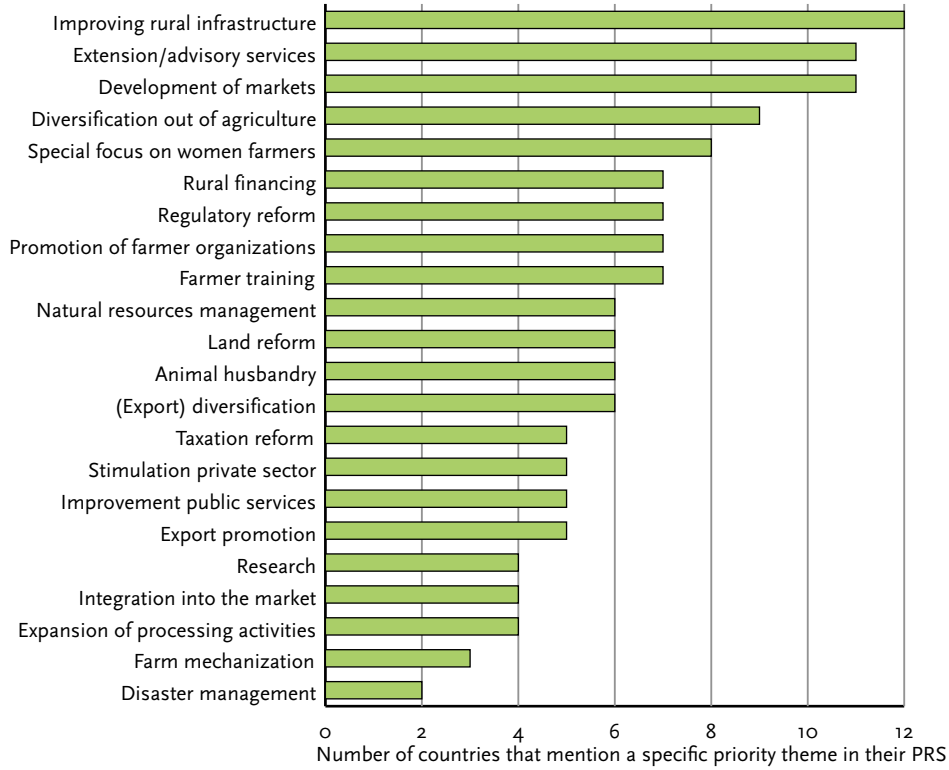


Figure 5.2 Agricultural priorities as reflected by the poverty reduction strategies (PRS) of 24 African countries. Source: Roseboom et al. (2004)



The Study Panel notes that there now may be a window of opportunity for the renewal of the priority accorded to agricultural research with the New Partnership for Africa's Development (NEPAD, 2002). The NEPAD strategy, which has been agreed to by African heads of State, includes:

- Poverty eradication and achievement of food security (including both availability and affordability);
- Establishment of stable and dynamic domestic, intra- and inter-regional, and international agricultural markets;
- Enhancing productivity and competitiveness of African farmers and agricultural business entrepreneurs;
- Africa becoming a net exporter of agricultural products;
- Achieving an equitable distribution of wealth;
- Africa being a strategic player in agricultural biodiversity management and development through the application of science and innovation;
- Africa taking the lead in the application of practices that conserve and sustain the natural resources used in agriculture;
- Ensuring an environment that is conducive for the development and expanded activity of the private sector, with a particular emphasis on the development of domestic entrepreneurs;
- Promoting and substantially increasing foreign direct investment and trade, with a particular emphasis on exports of high-value products;
- Developing micro, small and medium agricultural and agriculture-related enterprises, including in the 'informal' sector.

The NEPAD strategy recognizes that expansion of the agricultural land area will continue to be a component of agricultural development strategies. The plans and strategies of national agricultural research systems and the subregional organizations, however, emphasize the need for increased land and labour productivity. Each of these goals imply very different agricultural and land-use strategies. This fact illustrates the need for more clarity in sectoral R&D strategies, priorities and policies. The critical elements of these frameworks would include (a) the role and contribution of agriculture in the overall national economic and social development strategy; (b) the importance given to science and technology in agricultural development; and (c) concrete suggestions for improvements in the investment and organization of agricultural s&t research, extension, information and technology exchange systems, and primary, secondary and continuous education systems.

To achieve the above would be a daunting task in any country. However, the Study Panel believes that African and international capacities are suf-



ficient to undertake these reviews and ensure the articulation of policies, strategies and implementation plans for the advancement of science and technology and, more importantly, for the development of impact-orientated institutions.

A Comprehensive African Agricultural Development Programme (CAADP) has been formulated under the auspices of NEPAD through dialogue and debate among Africa's agricultural researchers, policy makers and the international community. FARA is poised to become the focal point for the NEPAD agricultural research strategy under the CAADP. The four priorities of CAADP are:

- Extending the area under sustainable land management and reliable water control systems;
- Improving rural infrastructure and trade-related capacities for market access;
- Increasing food supply and reducing hunger; and
- Expanding agricultural research, technology dissemination and adoption.

The fourth priority of the CAADP is derived from the Vision for African Agricultural Research (SPAAR/FARA, 1999), which suggests that agricultural production should grow 6 percent annually to improve food security and reduce food imports while producing the necessary surplus for an agriculture-led industrialization. To achieve such an ambitious growth in agricultural output a broad range of measures are needed, including improvements in macro-economic and agricultural policies, development of markets, investments in rural infrastructure, education and health, as well as improvements and additional investments in the generation, dissemination and adoption of new technology. A target is also set to double investments in agricultural research investments in 10 years time.

Advocacy and leadership

It is not sufficient to have the agricultural science communities formulate strategies, plans and programs, if those to whom they are responsible do not accord them the priority they deserve. The Study Panel detected that in general, agricultural scientists were not providing the leadership and political advocacy that is required to move agriculture, and especially agricultural research and development, forward in Africa. They are too timid to advance either their own interests or the welfare of African agriculture. They may offer disillusionment and disincentive as excuses, and the Study Panel has some sympathy with that view. However, agricultural scientists



need to adopt a more proactive, tenacious and innovative attitude, and should lobby their professional associations and academies of science to achieve the following:

- *African Union and Regional Economic Commissions.* Agriculture should be included as a regular discussion point on their working agenda. Continental-level reports on the state of African food security and science can be discussed with a focus on assessment, based on established goals and a common set of indicators with respect to trends in agricultural growth and productivity and the national, regional and international levels of investment in agricultural research. The African Union and Commissions should ensure the establishment, appropriate staffing and functioning of the relevant units supporting agriculture, s&t policy coordination and management, and thus provide the high-level oversight proposed.
- *International advanced research centres.* A stronger regional presence of the international advanced research centres is required in Africa with a minimum critical mass of senior scientists from all relevant divisions. This applies not only to the commodity improvement centres with headquarters out of Africa, but also centres like IFPRI, International Service for National Agricultural Research (ISNAR) and International Plant Genetics Resources Institute (IPGRI). Indeed, the Study Panel supports the recent decision to merge ISNAR and IFPRI, especially towards a strengthened African program. The strategic approach of these institutes for engagement must be for a long-term embrace-and-sit approach, rather than the hit-and-run of the project mode that has been forced upon them in the last 10 years or so. This is going to require a return to more assured core funding, with international investors providing long-term institutional program support, which leverages incremental contributions from African governments and successful competitive funding applications.
- *International organizations.* There is need to streamline and harmonize national agricultural and s&t data generation and management to facilitate the monitoring and evaluation required to assess the impact-orientation of R&D institutions. Specifically the Food and Agriculture Organization (FAO) should revise and upgrade information management systems for African countries to best practices such as those developed for the countries in transition. New methodologies and training programs will be required for area, yield and production estimations to cater for the di-



verse mixed intercropping complexities in African smallholder agricultural systems.

- *Forum for Agricultural Research in Africa*. One role for FARA must be to provide leadership in establishing alternative financing mechanisms tailored to African priorities and strategies that will promote partnerships amongst the many stakeholders at all levels. FARA should be an advocate for agricultural research in Africa, serve as a credible source of information on regional priorities, programs, best practice and success stories; and facilitate intra-continental and international collaboration. It is encouraging that FARA is evolving to play such roles. International investors should recognize and support FARA in its evolution as a strategic coordinating entity for the development of African agricultural research within the context of NEPAD.

Current NARS reform agenda

Enhancing the impact of science and technology in African agriculture is not only a matter of more resources, but also of using those resources more efficiently and effectively. Since the 1970s, there have been efforts to improve the performance of national agricultural research systems throughout Africa. Reforms of the 1980s and 1990s emphasized consolidation of research capacity and improvements in the internal organization and management of agricultural research, while the more recent reforms tried to make agricultural research organizations more outward looking, client oriented and impact driven. In its consultations in Africa, the Study Panel detected a considerable amount of ‘reform fatigue,’ both among senior management and scientists. They have seen resources for research continue to erode in spite of the proliferation of new models and paradigms. All this has left most of them demoralized and confused.

A recent review of NARS reforms in seven African countries (Cote d’Ivoire, Ethiopia, Ghana, Kenya, Senegal, Tanzania and Uganda) identified five major reform themes that dominate the current agenda (Chema and Roseboom, 2004; Chema et al., 2003), namely:

1. Redefining the role of governments in agricultural research,
2. Decentralization of agricultural research,
3. Stakeholder participation,
4. New and emerging forms of research funding, and
5. Strengthening of system linkages.



Role of governments

‘The most fundamental element of a science agenda for Africa is a genuine political will and vision, consistent with the objectives of the agenda, which acknowledges that science and technology are credible tools for solving our problems,’ says Prof. Turner T. Isoun, Honourable Minister of Science and Technology, Federal Republic of Nigeria.

The global trend to critically examine the legitimate role of government has affected African R&D institutions. New forms of sharing the responsibility are being examined, so that those who benefit most also share in the costs and reduce the fiscal burden on taxpayers. Research on export crops has a long tradition of close private-sector involvement, because producers of exports generally reap most of the benefits of research and development on these commodities. Hence, they are more willing to fund all or part of it. Six of the seven African countries studied (the exception being Ethiopia) revealed a reinforcement of shared responsibility between the government and the private sector for research in recent years on commercial/export crops. In addition, a complete privatization of research on coffee, tea and tobacco is under way in Tanzania and of research on sugar in Kenya. In Tanzania, even extension in tea is being privatized.

With non-tradable food commodities, consumers are often the main beneficiaries of research and development in terms of reduced prices. As a result, producers have been less willing to fund research and development involving these crops and public funding has been the primary source of support. However with trade liberalization and market-led/farmer-driven R&D agendas, the possibility of turning previously non-tradable commodities into tradables becomes more likely, increasing the incentives and scope for producer support for agricultural research and development.

New public management ideas and concepts, which have strongly influenced the current NARS reform agenda, argue for a clear separation between funding, priority setting and implementation functions within government. The establishment of autonomous or semi-autonomous NARIS in Africa during the past 25 years, for example, has resulted in a separation of research funding from priority setting and implementation.

In several African countries, the responsibility for priority setting in agricultural research has been delegated to either external committees composed of farmer and industry representatives (e.g., Côte d’Ivoire, Senegal) or to democratically elected district councils (e.g., Uganda, Tanzania). The expectation is that by giving stakeholders control over the research budget, agricultural research will become more impact oriented.



The Study Panel views these as desirable developments while noting the following caveats:

- Mobilization of private sector resources for research should not be viewed as an opportunity to reduce the government's own contributions to research of a public-good character.
- Smallholder farmer organizations are weak in Africa and hence it will be difficult to mobilize them to articulate priorities and effective demands for agricultural research, as laudable as this might be.
- It is not clear that stakeholder sovereignty in research priority setting will automatically lead to a research agenda with higher impacts on the poor and food insecure.

Decentralization

The decentralization reforms of national agricultural research systems take place at various levels: first, to lower levels of government or to specific interest groups; second, a geographic decentralization from national headquarters to district centres; third, the devolution of decision-making within organizations to the lowest pertinent level (the principle of subsidiarity). The second type of decentralization has gone further than the other two and has enhanced the extent of more applied/adaptive production systems and multidisciplinary research conducted in the process. The headquarters locations tend to focus more on disciplinary or commodity research at the more strategic end of the spectrum. An added advantage of geographic decentralization can be increased relevance of research and development because of the proximity to the clients, but conversely it can reduce cost-effectiveness of research. Moreover, convincing good quality scientific staff to relocate to more remote regions with poor research and general infrastructure has proven a challenge.

Another factor, arguably a more limiting one in the decentralization of agricultural research capacity in Africa, is the small numbers of researchers employed relative to the farmer population. In Africa the agricultural population-to-researcher ratio in agriculture ranges from 2,500 to 50,000, numbers that clearly illustrate that there is a limit to how close one can bring research to farmers. For comparison, the ratio in developed countries was about 400 in the early 1980s (Pardey et al., 1991) and has most likely further declined in recent years. These figures do not include the researchers employed by private agricultural input and processing industries. Their inclusion would sharpen the contrast in research capacity even further.



The interaction between farmers and researchers in the developed countries is of a completely different order to that of most African countries. Farmers in developed countries are relatively few (2-5 percent of the working population), are well-organized, can articulate their technology demands, make use of the latest communication and information technologies, and can be reached easily through the market or their own professional organizations. Most developed countries are now moving towards consolidation of agricultural research capacity in fewer locations because being physically close to the farming community has become less relevant. This situation does not currently apply in African countries.

The proposed ACARE, if adequately resourced, will complement the trend to decentralized, participatory/adaptive research by national agricultural research systems, by providing economies of size in the conduct of strategic research on pervasive priority problems of a regional or continental character, where spillovers are possible. The participatory knowledge quadrangle is intended to bring them together with other stakeholders. In a sense, the ACARE, international advanced research centres and the advanced research institutions will be trying to raise attainable and potential productivity levels with partners and in the process create more de facto yield gaps, as described in Chapter 3. The participatory knowledge quadrangle (PKQ) will be vital in trying to close such gaps thus increasing productivity and improving food security.

Increased stakeholder participation

Perhaps the most challenging of the five reform themes in Africa is to make agricultural research more client oriented and client driven through stakeholder participation. There is a general tendency to equate stakeholders solely with farmers. However, consumers, industry, and NGOs and CBOS are also important stakeholders that may wish to influence the agricultural research agenda. Three levels of stakeholder participation in agricultural research can be identified:

1. Stakeholders are consulted in the determination of research priorities and often also in the research process itself.
2. Stakeholders actually control the allocation of the research budget.
3. Stakeholders participate in the funding of agricultural research and hence have a strong incentive to control proper allocation and use of the resources.

Most of the stakeholder participation in Africa is of the first type, that of voluntary consultation. The second type of farmer participation is still relatively rare, but increasingly being promoted by the World Bank and a few



other donors. The third type of farmer participation is quite common in Africa for research on commercial (export) crops. The World Bank sees important advantages in the (co-) financing of agricultural research by farmers. Besides the argument that those who benefit should pay, it is also an effective way to secure close involvement by farmers in the selection of research priorities. But in these commodity-specific research schemes, there is a risk of major and often unresolvable conflicts over the research agenda between, for example, smallholders and large plantation owners.

Farmer participation is taking place in the problem identification and priority-setting phases of agricultural research, and increasingly during the implementation and evaluation phases. Participatory research approaches are being promoted strongly throughout Africa, but they are ineffective as technology transfer mechanisms because they only reach a tiny fraction of the farmers, and tacit knowledge does not easily extend to other farmers. Participatory research is an improvement on the old supply-driven linear research models and tends to work well for the small (although often economically important) minority of African farmers who are integrated into the market, well organized and capable of articulating their needs.

Experience in countries such as Kenya, where promotion of farmer organizations has been on-going for several decades, indicates that maintaining them as functional entities is difficult. Smallholder farmer organizations for food crops (or non-commercial, livestock-keeping pastoralists) and government-sponsored cooperatives have generally not proved to be a success (Hussi et al., 1993). More recently, Côte d'Ivoire and Senegal have adopted the most far-reaching plans to involve farmers and farmer groups in agricultural research guidance. However in these cases, the poorest farmers (i.e., those engaged in subsistence food production and livestock keeping) have no prominent roles in the proposed models. Unless specific efforts are made to advance in this direction, encouraging smallholder participation that will generate a coherent voice to guide research is likely to remain elusive in the near future.

The sheer numbers of smallholders relative to researchers, their lack of organization, the huge social and cultural diversity, the complexity of their farming systems and their unarticulated technology needs place them at the periphery of the agricultural innovation system. New thinking is needed to determine whether the research and extension linkages as currently conceived (and which, at best, will reach only 10-20 percent of farmers) have any likelihood of ever solving this problem. Currently subsistence farmer needs are largely unknown, but they are likely to require a mix of



skills currently scarce among agricultural science graduates. It is axiomatic that an essential ingredient in solving the problem lies in the level of organization of smallholder farmers. Intelligent research on their different ways of social organization should provide clues as to how to help advance and stimulate what should be a diversity of forms of organization.

The more enterprising smallholders in Africa are becoming more market-oriented producers and most actively pursuing strategies of income diversification beyond agriculture. Apparently, African rural households are increasingly turning to non-farm activities in order to meet their needs for cash income. This has major repercussions for farming as it has to compete within the rural household for labour and capital (Bryceson, 1999; 2000). Often the most able workers in the household (young men and women) pursue non-farm activities, leaving farming to the women, children and the elderly.

Bryceson's study indicates there is a withdrawal of such households out of commercial agriculture back into low-external-input subsistence agriculture (Bryceson, 1999; 2000). She argues that the economic liberalization policies adopted in the 1980s and 1990s (i.e., elimination of input subsidies, dismantling of marketing boards) have worsened the conditions for using improved technologies. This sketch of developments among rural households in Africa makes clear that there are substantial differences among African smallholders regarding their interest in developing and adopting new agricultural technologies. Orthodox farmer participation mechanisms may easily overlook such differences.

New funding mechanisms

In the early 1990s, the Special Program for African Agricultural Research (SPAAR), USAID and the World Bank formed a coalition to promote new ways of financing agricultural research in Sub-Saharan Africa through the Sustainable Financing Initiative. Initially the emphasis of this initiative was on identifying alternative sources of funding for agricultural research. Debt swaps, endowment funds, and generation of income through commercialization of research results were some of the ideas that were contemplated. However, the idea of the Sustainable Financing Initiative that has attracted most attention is that of competitive research funds for agricultural research.

Abt Associates conducted for USAID a series of country case studies into competitive funding schemes (Brinkerhoff et al., 2002). Gill and Carney (1999) conducted a study for the U.K. Department for International Devel-



opment on competitive agricultural technology funds in developing countries. In recent years, this new funding mechanism has received significant support from various donors and the World Bank. A competitive research fund is now included in (basically) every World Bank project dealing with agricultural research in Africa. Not only at the national level but also at the regional level, competitive research funds are becoming increasingly fashionable.

Possible advantages of competitive research funds are:

- Closer alignment of research activities with (regional, national or subnational) research priorities;
- Increased effectiveness by directing resources by scientific/technical merit (peer review);
- Increased efficiency by reducing costs and increasing accountability;
- Facilitating cross-institutional or cross-national collaboration; and
- Mobilizing underutilized capacity where salaries currently represent the bulk of institutional funding.

However, there are also possible disadvantages such as:

- Most competitive research funds in Africa do not have a secure, local funding basis which means long-term research may suffer (heavy donor dependence).
- Given the small size of research grants, transaction costs can be a high proportion of funding, particularly in the early stages.
- It is a financing instrument that is suitable for a (specific) part of the research agenda, but not for the whole agenda.
- The instrument requires relatively mature research organizations that can handle research contracts.
- The instrument does not work in small research systems due to lack of competition.

The two countries with the most ambitious competitive research fund plans are Côte d'Ivoire and Senegal. Their plan is to consolidate all agricultural research funding from government, donors, and the private sector in one national competitive research fund in the medium to long term. The committee managing this fund should set research priorities for the complete national agricultural research system. However, it is questionable whether such a highly centralized approach is desirable. Elliott (2000), for example, argues that competitive research funds can be a valuable complement to institutional funding but not substitute for it. The new Multi-Country Agricultural Productivity Program (MAPP) funding initiative of the World Bank for African agricultural research has a significant component of competitive grant funding.



A financing instrument sparsely used in Africa is that of a matching grant scheme, where the government matches on a 50:50 basis the agricultural research funding mobilized by farmer organizations, commodity organizations, NGOs, private industries, and others. This instrument turned out to be quite effective in mobilizing funding from local districts and NGOs for the Zonal Agricultural Research Funds in Tanzania, but this is the only known country utilizing matching grant schemes.

In addition to new funding mechanisms, one can also notice a shift in existing financing instruments away from general government funds and towards specific levies, own income, local government, and commercial contracts. For example, research-specific surcharges (either voluntary or legally enforced) are making their comeback.

Strengthening system linkages

As mentioned earlier, in most countries, research-extension linkages are problematic due (in part) to the collapse or the poor state of agricultural extension. The much-promoted training and visit approach has been disbanded in recent years, but no apparent promising alternative has yet emerged. There are quite a number of success stories on technology diffusion initiatives in African agriculture (e.g., Sasakawa-Global 2000, African Highlands Initiative, Agricultural Technology and Information Response Initiative), but the upscaling of such approaches tends to be difficult and often prohibitively expensive. Hence, there is currently little consensus of how to tackle the problem of technology diffusion; what is clear is that the traditional, government extension services have outlived their usefulness, and in particular the one-size-fits-all approach. Haug (1999) has undertaken a pertinent overview of agricultural extension. A greater diversity in technology delivery systems is being called for, as well as more stakeholder participation, as mentioned earlier. Some possible innovations are described in Box 5.2.

Encouraging extension

Agricultural extension, vital to the diffusion of new technology, is currently moribund in many African nations. Kenya has 12,000 extension agents but lacks operating funds to buy petrol for motorbikes. Zimbabwe recently merged its research and extension services but inter-service rivalries remain unsolved. Box 5.3 gives some insights into the way forward for Africa. There is a need for more research on the future of extension systems in Africa and the scope for designing private models. Here the International



Service for National Agricultural Research can be especially helpful in distilling experiences of the past and experiments of the present into best practice options.

Coordination through an integrated systems approach

Most well-trained agriculturalists have the intellectual capital that allows them to move between research, education and extension functions. Moreover, experience shows that each of these elements must be effective and interlinked for the agricultural sector to move forward. Specialists in institution-building have recommended a systems approach to coordinating and sequencing interlinked investments in agriculture's three pillars (research, extension and education). This approach has been variously called an agricultural knowledge system (Röling, 1988), an agricultural knowledge information system (FAO and the World Bank, 2000) and the agricultural knowledge triangle (Eicher, 1999). The Study Panel goes one step further and advocates a knowledge quadrangle, where linkages to farmers

Box 5.2 Institutional innovations

Numerous innovations in institutional development in the developing world are either in pilot phases or have become part of the arsenal in agricultural research and development.

Two of the more daring institutional innovations currently under way in this area are the privatization of extension services in Côte d'Ivoire, Senegal, and Uganda; and the introduction of extension cost-recovery schemes in Ghana and Tanzania. Both institutional innovations will affect the research–extension linkages profoundly. This scheme may operate successfully under circumstances where the farmers can afford the payment required for the extension service. However, it is very doubtful whether poor smallholder farmers will benefit from these institutional innovations. There is a risk that they will be further marginalized.

Uganda established a *National Agricultural Advisory and Development Services (NAADS) project* in 2001 with the intention of introducing demand-driven agricultural extension services. Funds flow from donors and the treasury to districts, sub-counties, and farmers' organizations, which then contract extension agents and NGOs for required information and services. This system acknowl-

edges that poor smallholders will not have the resources to fund all of their extension needs, yet there is a need for them to be empowered to drive the process, a departure from the failed publicly-funded top-down systems of the past. Malaysia has had a *market-led agricultural R&D* program since independence that has transformed productivity and created new comparative advantages and market niches. The *Lab-to-Land-to-Lab* program in India was instituted to encourage scientists to relate more explicitly to farmers both in the development of technology options and in assessing their worth. In recent years, with increasing graduate unemployment, India began knowledge-based employment schemes. The *agri-clinic* program encourages new graduates to work in villages to provide services like soil and water quality testing, animal health and integrated pest management to farmers for a fee. *Agri-business centres* help farmers to process and market their produce also for a fee. The government guarantees loans by development banks to establish the businesses at concessionary interest rates.

Latin American countries have introduced an array of institutional innovations that have made them more *plural-*

istic, accountable and sustainable. This process began with substantial reductions in public funding of agricultural research that forced managers of national agricultural research systems to seek new revenue sources and increase partnerships with universities, NGOs and the private sector. Wageningen University in The Netherlands has instituted a *Sandwich PhD Fellowship* program that allows the graduate student to spend most of the research phase of the program in the home country instead of at Wageningen. This is described in greater detail in Chapter 6.

FAO and others have been experimenting successfully with Farmer Field Schools (FFS) in Kenya and other African countries using a diversity of approaches. These build on the earlier models of integrated pest management introduced in Asia. These Schools empower farmers at the same time as they convey new technology options. Another innovation is the emergence of farmer groups oriented around community cereal banks that can be linked to FFS to help ensure a market for any new production surpluses that follow from the adoption on FFS-mediated technology options.



are given much greater prominence.

The development and diffusion of new technology is critically dependent upon the coordinated, cumulative performance of research, education and extension. Since the functions represent complementary investments, they should be planned and sequenced as a system rather than as separate activities. Also, since they are risky investments with long-term payoffs, the government is usually the main investor in all three pillars at early stages of economic development. Government investments in research produce public goods such as new technologies that generate spillovers and bring benefit to more than one socio-economic group now and in future generations. Thus a systems approach is needed to pragmatically craft agricultural knowledge systems that promote communication, interaction and cooperation between agricultural higher education, research, extension and the farmers.

Despite this logic, most donors in Africa have persisted in pursuing a pillar-by-pillar approach to strengthening rural institutions. Why? A former extension specialist in the World Bank states (Venkatesan, 1991):

The Bank's involvement with the development of higher agricultural education at the university level in Africa has been minimal...within the

Box 5.3 New thoughts on agricultural extension

Three models of agricultural extension have dominated extension debates in Africa since independence. First the quantitative model was introduced in the 1960s by Western experts who assumed that new technology from temperate climates could be more rapidly transferred to Africa and diffused to farmers if the number of extension agents was dramatically increased, but this model collapsed through poor management, a lack of new technology to extend and problems of financing the expanded system.

Kenya was the testing ground for the second model of extension – the Training and Visit (T&V) model, which was a highly centralized attempt to improve the management of national extension systems. A recent review by the World Bank concluded that 'The performance of the T&V system as applied in Kenya

has been disappointing. The system as implemented has been ineffective, inefficient and unsustainable' (Gautam, 1999). The rise and fall of T&V extension in Africa offers a sobering example of the need for pilot projects, independent Africa-wide evaluations and attention to its fiscal sustainability prior to implementation.

Today, African agriculturists are more seasoned and less gullible in accepting the proposition that one extension model can serve the diverse needs of 54 countries in Africa. A third extension privatization model now being pilot tested in Mozambique and in the early stage of implementation throughout Uganda (Nahdy et al., 2002) is being driven by five imperatives: (a) many of the national extension programs are starved for funds because of reduced government budgets; (b) another option was needed

once donor-financed T&V schemes became unsustainable after foreign aid was phased out; (c) private extension has been effective for export crops where farmers are taxed to finance both research and extension; (d) many village and church groups in Africa set up their own extension networks after the collapse of T&V programs; and (e) private extension is spreading in industrial countries such as the Netherlands, New Zealand and the United States.

Mozambique is playing a leading role in southern Africa in contributing to a climate of debate on building African models of extension (Gemo et al., 2003). The National Directorate of Rural Extension (DNER) is currently pursuing a 'learning-by-doing' approach to build Mozambican models of extension, including privatization (Eicher, 2002).



Bank, the agricultural divisions have no responsibility for universities, which are the responsibility of the education divisions... it is not therefore surprising that the Bank projects in extension and research do not provide support to higher agricultural education.

The World Bank made only three agricultural higher education loans in Sub-Saharan Africa from 1987 to 1997 (Willett, 1998). Nevertheless, the World Bank prides itself as being a 'knowledge organization.' The Bank may need to take steps to shore up its credibility on the issue.

Beyond research to knowledge and innovation

Because of a greater emphasis on impact in general (and that on poverty, hunger and malnutrition in particular), the analytical perspective in s&t strategies has shifted during the past decade from *agricultural research* (the NARS perspective) to *agricultural knowledge and information systems*, to *national innovation systems*. While each of the three system concepts has its own strengths and weaknesses, they can be seen as interlinked. The NARS concept focuses on the generation of knowledge; the second concept on the generation *and* diffusion of knowledge, and the latter concept on the generation, diffusion *and* application of knowledge.

The third perspective comprises a far broader set of actors than the traditional agricultural research, extension and education agencies. Innovation takes place throughout the whole economic process and not all innovations have their origin only in formal science and technology. This new perspective places more emphasis on the role of farmers, input suppliers, transporters and processors in the innovation process. It rejects the traditional linear model of the research-extension-farmer linkage, which is highlighted by the apparent failure of the Training and Visit system in Africa and India.

A new paradigm is called for which recognizes there is a need for a process of generation and diffusion of knowledge, with active stakeholder participation, management and perhaps ownership (i.e., privatizing research and extension systems). Case studies now exist in the Agricultural Research Institute of Senegal (ISRA) and the Tea Research Institute of Tanzania (TRIT). The national agricultural research systems are no longer seen as the epicentres of innovation but as one of its various sources. Knowledge and information may spill into the innovation system from other sources than the national agricultural research systems, and, perhaps even more crucially, knowledge and information may emerge outside the realm of



formal research because of on-farm as well as off-farm learning (up and down the agricultural production chain) by doing, using, or interacting. This third perspective, as part of a new strategy for agricultural research and development in Africa, attracts the Study Panel.

It makes good sense to design a system that embraces the participatory knowledge quadrangle (PKQ), combining farmers, research, education and extension rather than investing in one pillar at a time. Numerous studies have shown that the pay-off to investment in agricultural research, extension, or agricultural higher education in a specific core agricultural institution will be higher if the investments are coordinated and sequenced. In practice this means designing an organizational structure that facilitates 'connectivity' between the complementary institutions and a reward structure that encourages managers, scientist and academicians to communicate and cooperate with each other (even when the managers report to different ministries) and foster linkages with farmers.

To be effective, the national innovation system paradigm will require major investments in information and communication technologies, along with a change in university curricula and in the role and relationships between NARIS, extension systems and universities (Box 5.4). At present extension systems have little linkage with either NARIS or universities in most African countries. The 'farmer-research-education-extension quadrangle' is the foundation for the future, to build an integrated national agricultural research, education and extension system (NAREES) that involves and empowers smallholder farmers. After all, the collective goal of such a system is to increase agricultural productivity and benefit all members of society through lower food prices, food security, income generation and employment (Bonnen, 1998).

Electronic Delivery of Agricultural Information to Rural Communities in Uganda aims to package and deliver appropriate information to farming communities through existing telecentres in various cities. Such information includes farm stock prices, weather reports, early warning of pests and diseases, market information, new technologies, sources of credit and training. It is expected to revolutionize information exchange between extension workers, farmers, community-based and nongovernmental organizations, unions and cooperatives.

There is a need for pilot programs in the institutional innovations implied by the framework of the participatory knowledge quadrangle to explore the most effective ways to implement them. This will differ among countries. Here again there is a potential role for ISNAR in distilling from



the experiences of others, such as those cited in Boxes 5.2 and 5.3, in action research to provide best practice guidelines.

Public-private partnerships

The role of the private sector can be enhanced by innovative public-private partnerships. Intellectual property rights remain a significant constraint in these endeavours but can be successfully addressed. One solution is for the private sector to provide patented processes and materials free to African public institutions. Institutional innovations such as the African Agricultural Technology Foundation (AATF) can provide strategic opportunities to encourage these partnerships (see Box 4.10 in Chapter 4). To facilitate public-private partnerships beyond this, there is a need to invest in basic communications and transport infrastructure, as well to cultivate a climate of trust that is currently lacking between the two sectors.

The private non-farm sector could play a key role in supporting the provision of extension, especially at the post-harvest end of the spectrum in the market-driven productivity improvement paradigm suggested in this report. This would be facilitated if smallholders become active and dominant stakeholders in post-harvest enterprises through cooperatives and the like. Again there is an action research agenda for ISNAR in synthesizing experiences with such initiatives elsewhere and formulating best practice options for Africa.

Box 5.4 Roles of information and communications technology in the participatory knowledge quadrangle

In India an experimental network has connected more than 20 isolated rural villages to a wireless Internet service. About half the population in most of these villages has a total family income of less than US\$25 per month. The project aims to provide knowledge on demand to meet local needs using information and communications technology, and it does so through a bottom-up process. Volunteer teams help poll the villagers to find out what knowledge they seek. Particularly popular so far are women's health information, advice on growing local crops and disease control, the daily market prices for these crops, local weather forecasts, and information about government programs to aid poor families.

An expanded concept of a global electronic network is envisioned that connects scientists to people at all levels – farmer organizations and village women, for example. The project aims to show that empowering people through access to timely and relevant information can make a difference in the life of the rural poor, and that new information and communications technology can play a crucial role in this effort. A unique feature of the project is the fact that most information is collected and fed in by the local community.

Similar stories are emerging from Africa. An example is the Mapping Pastoral Movements in the Sahel, where the population has access to information on

how to use their pasture resources effectively during the dry season. Tools such as geographic information systems (GIS), global positioning system (GPS) and thematic maps of seasonal movements of livestock reinforce the identification of relevant know-how. Effective methods of livestock farming incorporating information and communications technology are identified. These help to reduce conflicts between growers and breeders and to alleviate animal pressure on pasture lands, while enhancing the productivity of traditional livestock farming, with the direct consequence of increasing family income.



Lead from government

Governments should take the lead to identify areas that overlap public- and private-good research and facilitate negotiation of flexible agreements to manage joint design, conduct and financing of research. Mechanisms for equitable benefit sharing need developing in a manner that encourages African entrepreneurs to engage in enterprises that result in new rural non-farm income-generating opportunities.

It should be recognized, however, that there will always be a public-good agenda (genetic resource conservation and management, agricultural and s&t policy research, etc.) for which the private sector will have no incentive to become involved. Hence public-private partnerships may not be a panacea to offset declining public funding of all agricultural research and development. There is also a need for transparent and attractive incentive and reward systems for scientists, to encourage them to pursue such partnerships.

Exploiting synergies

At best there are weak linkages between national agricultural research institutes and the universities in Africa – often they are non-existent. This represents a failure to exploit synergies when there are acknowledged human and financial constraints to effective agricultural research and development in the national agricultural research systems. One difficulty is that they are mostly in different ministries (agriculture and higher education) hence a national perspective is necessary. Obviously, there is a role for national councils of science and technology and/or a scientific adviser to the Prime Minister to help address such issues.

Universities should be regarded as key components of national agricultural research systems and participate actively in national and regional agricultural R&D-priority setting, and in the emerging competitive and other funding mechanisms being proposed under the MAPP initiative of the World Bank. Such initiatives should ensure that basic research does not miss out, as often short-term impacts are emphasized, while basic and strategic research is by nature long term. Universities in consultation with NARIS should review undergraduate curricula to ensure that the students gain an understanding of the constraints and opportunities in smallholder agricultural/farming systems (as opposed to reductionist curricula more relevant to large-scale commercial farms in the linear research–extension model now increasingly being questioned).



If competitive grant funding mechanisms are to minimize tensions among institutions vying for resources, they need to be structured to especially reward creative asymmetric partnerships that include weaker actors such as the smaller NARS. The formation of such teams with common interests in competing for grants and collaborating in jointly-funded research projects can be a strong unifying force, as evidenced by the success of the Australian Cooperative Research Centre (CRC) model described earlier in this chapter.

Participatory/diagnostic on-farm research approaches and knowledge and information management techniques using information and communications technology are strategies for equipping graduates to play more entrepreneurial roles. They may help to foster smallholder organizations and work with them to make e-farming a reality. The <i@mak.com> reform at Makerere University in Uganda is an innovative approach. Graduate students undertaking thesis research could be located at accredited NARS for the conduct of their research, thus exposing them to the real national/regional priority problems of smallholders.

Effective farmer organizations

To complete the generation and diffusion of the knowledge triangle requires effective farmer organizations to form a quadrangle. In Africa there are too few smallholder farmer organizations to ensure their full participation as key stakeholders in national, regional, continental and international agricultural R&D-priority setting. Options that should be considered include:

- Changes to the university curricula as described above;
- Political commitment to the promotion of smallholder farmer organizations;
- Revisiting the role of cooperatives, especially the scope for them to improve the efficiency of markets for inputs and outputs, achieving economies of scale in purchasing, sales, credit delivery and extension;
- Identification of smallholder 'champions' among scientists and the general community;
- Active involvement of national agricultural research systems, subregional organizations and FARA in this endeavour;
- Have ISNAR include this as a major element in its new action research program in Sub-Saharan Africa.

Is it possible that successfully organized smallholder associations that become effective 'stakeholders' in agricultural research and development,



driving the agendas and reaping resulting benefits, will evolve into politically savvy advocates for increased public agricultural R&D funding? Their large numbers make it quite feasible where democratic reforms and improved governance have taken place. Hence the returns to national agricultural research systems in actively promoting smallholder organizations could be quite large and the ‘transactions costs’ in generating increased effective demand for agricultural research and development in this manner should be viewed as an ‘investment,’ with the dividend being increased public R&D resources (supply).

Even if smallholder organizations that become stakeholders and participants in agricultural research and development cannot so influence the government through their votes, they may be prepared to finance more research and development themselves if they become convinced research institutions are indeed more responsive to their priorities and needs, and hence can deliver increased income to them. However, unlike farmers who are involved in cash export crops, smallholders primarily growing food crops for home consumption will be much more difficult to convince about financing all or part of the agricultural research and development, as free riding will be a problem and a large share of the benefits of research and development will accrue to consumers, thus reducing the incentive for smallholders to self-fund.

Agricultural R&D investments

Reliable quantitative data on agricultural research investments and their impact are in short supply around the world and particularly so in Africa. This section summarizes and analyzes the quantitative but often incomplete and scattered data available on Africa and, where possible, compares them with comparable data for other parts of the world. The focus is on more detailed S&T investment data recently compiled by the CGIAR Agricultural Science and Technology Indicators (ASTI) Initiative for some 14 of 49 countries in Sub-Saharan Africa. Together these 14 countries represent close to 70 percent of the agricultural research staff as well as the value of agricultural output (AgGDP) in Sub-Saharan Africa – unfortunately ASTI does not have current data for North Africa.

Financial and human capital investments

Total agricultural research expenditures in Africa in 1999-2000 are estimated at US\$1.7-1.8 billion (in 1993 international prices) (Table 5.2). Some 70 percent of this is expended in Sub-Saharan Africa (Figure 5.1). In 2000,



the 14 countries in the ASTI sample spent US\$900 million (in 1993 international prices) and employed close to 7,000 full time equivalent researchers. Kenya, Nigeria and South Africa represent almost two-thirds of this. The distribution of the total number of researchers differs considerably from that of total spending, which resulted in large differences in total

Table 5.2 Composition of expenditures and researchers in agricultural research and development in selected African countries, 2000

Category	Spending in 1993 international dollars (millions)	Total FTE researchers	Spending per researcher in 1993 international dollars (thousands)	Number of agencies in sample
By country				
Burundi	6.7	76.6	87.3	7
Côte d'Ivoire	32.5	156.9	207.2	9
Eritrea	8.9	85.8	103.4	3
Ethiopia	71.4	742.2	96.2	31
Ghana	52.0	474.5	109.7	29
Kenya	135.3	833.3	162.3	26
Madagascar	8.1	206.2	39.3	16
Mauritius	23.6	153.5	153.7	16
Nigeria	111.9	1,351.7	82.8	84
South Africa	330.6	1,061.1	311.5	50
Sudan	36.1	861.7	41.9	29
Tanzania	25.9	542.3	47.7	12
Uganda	49.8	249.9	199.3	14
Zambia	8.0	192.4	41.6	16
Total	900.7	6,988.2	128.9	342
By institution				
Government	660.3	5,230.4	126.2	132
Nonprofit	62.6	244.4	256.0	62
Higher education	157.9	1,423.8	110.9	171
Private	20.0	89.5	223.3	24

Source: Beintema (2003).

Note: See ASTI country briefs for agency sample (www.asti.cgiar.org). Data for Côte d'Ivoire and Ghana are for 2001. The data were compiled using internationally accepted statistical procedures and definitions developed by the OECD and UNESCO for compiling R&D statistics (OECD, 1994; UNESCO, 1984). The Study Panel grouped estimates into three major institutional categories: government agencies, higher-education agencies, and business enterprises. The latter category comprises two subcategories: private enterprises and non-profit institutions. The Study Panel defined public agricultural research to include government agencies, higher-education agencies, and non-profit institutions (thereby excluding private enterprises). Agricultural research includes crops, livestock, forestry, and fisheries research, as well as agriculturally related natural resources research.



spending per scientist among the various countries in our sample. For example, resources per scientist averaged US\$311,000 in South Africa in 2000 – close to eight times the average for their colleagues in Madagascar, Sudan and Zambia. Generally, scientists employed by the non-profit organizations had more resources to hand than their colleagues working at the government and higher education agencies.

Most agricultural research is conducted by the government sector, which accounted for almost three-quarters of total agricultural R&D spending and staff (Figure 5.3).

The corresponding share of the higher education and non-profit agencies were 18 and 7 percent, respectively. Private agricultural research is still quite limited in Sub-Saharan Africa. The government sector has maintained its share of total agricultural R&D spending at around three-quarters since 1971, while the university share has risen from 10 percent in 1971 to 18 percent in 2000, largely as a result of expansion in the number of universities, especially in Nigeria and Sudan (Figure 5.4).

UNESCO (1998) reports that of all regions in the world, Sub-Saharan Africa has the second lowest research and development intensity per dollar of gross domestic product (GDP) – with a gross expenditure on research and development of only 0.3 cents for every dollar of GDP (only ahead of the Arab states that spend 0.2 cents per dollar). This level is only 12 percent of that in the United States, and only 21 percent of the world average. The low level of expenditure is reflected in low output, with African scientists producing only 0.8 percent of the world’s scientific publications. Africa’s share of patents in the world is close to zero. But it may get even worse

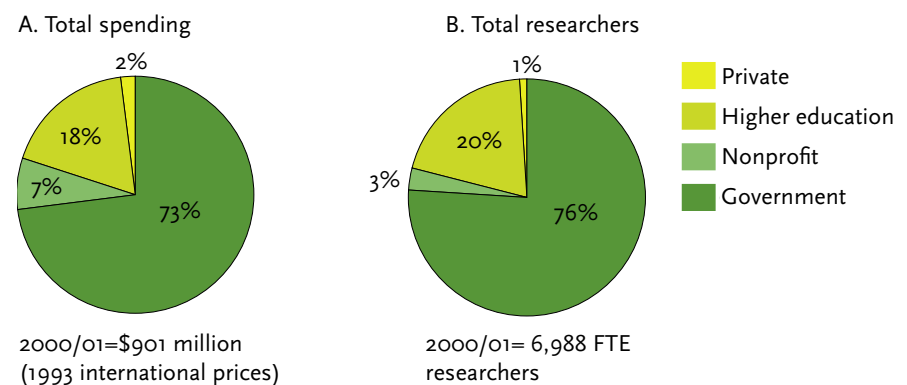


Figure 5.3 A-B Total African agricultural R&D spending and staff by institutional category, 2000-01. *Source:* Beintema (2003). *Note:* See Table 5.2 for sample size and notes.

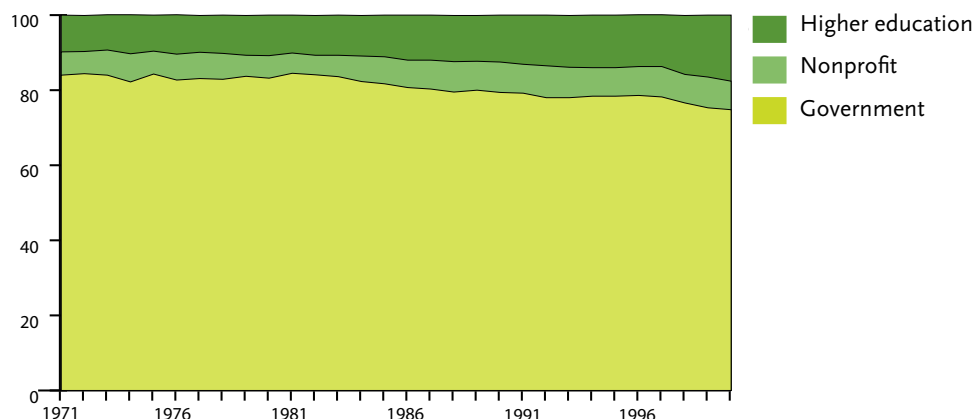


Figure 5.4 Trends in public spending by institutional category in selected African countries, 1971-2000.
 Source: Beintema (2003). Note: Country sample includes Nigeria, South Africa, Eritrea, Ethiopia, Kenya, Madagascar, Sudan, Mauritius, Zambia, Côte d'Ivoire, and Ghana.

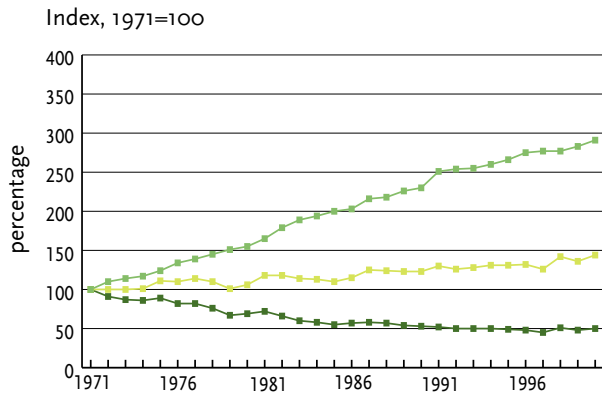
– UNESCO (1998) reports that Africa's share of scientific output fell by 19 percent from 1990 to 1995.

Agricultural research expenditures for a sample of 12 Sub-Saharan African countries continued to grow slowly at about 1 percent per annum during the 1990s. This was much lower than the growth observed globally (2 percent per annum) or for the developing world (3.6 percent) during the period 1991-96 (Pardey and Beintema, 2001). The growth in research staff in the 12 Sub-Saharan Africa countries during the 1990s fell to 1.7 percent per year from the much higher figures of 3.7 percent in the 1980s and 4.9 percent in the 1970s. For the past 30 years, the growth in research staff has exceeded that of expenditures, resulting in smaller expenditures per researcher. In real terms (i.e. corrected for inflation), expenditures per researcher were in 2000 only half of what they were in 1971 (Figure 5.5).

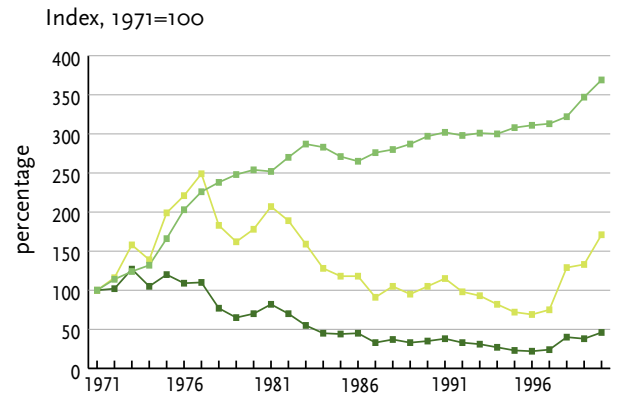
In 2000, 74 percent of the total full-time equivalent researchers in the 14-country African sample had postgraduate-level training, with close to one-quarter holding doctoral degrees. The large countries in our sample heavily influence these averages and the quality of research staff varies markedly among countries. For example, 30 percent or more of agricultural researchers in Nigeria, South Africa, Sudan, and Côte d'Ivoire held doctoral degrees while for Eritrea and Ethiopia about one-half of the researchers held only BSc degrees. A higher proportion of university staff held PhD



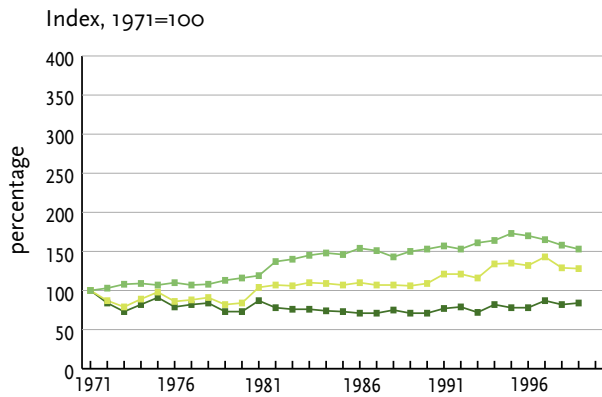
A. 12-country sample



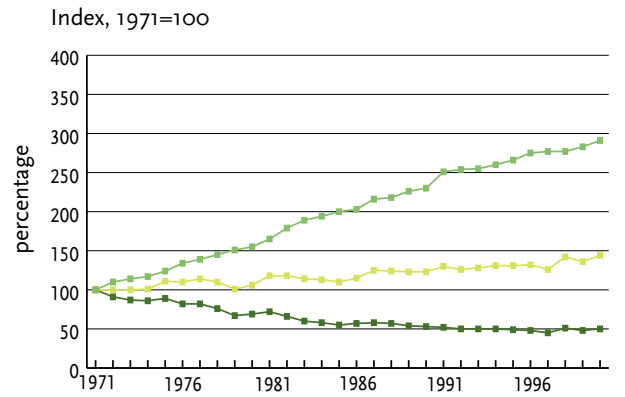
B. Nigeria



C. South Africa



D. 10-country sample



■ Researchers
 ■ Expenditures
 ■ Exp. per researcher

Figure 5.5 A-D Trends in public expenditures, researchers, and expenditures per researcher in selected African countries, 1971-2000.

Source: Beintema (2003). Note: Country sample includes Burundi (ISABU only), Côte d'Ivoire, Ethiopia, Eritrea (from 1991 onwards), Ghana, Kenya, Nigeria, Madagascar, Mauritius, South Africa, Sudan, and Zambia.



degrees compared with staff at other agencies, a pattern that was prevalent among most of the countries in the region and which is in line with other regions such as Latin America (Beintema and Pardey, 2001). During the 1990s, the quality of research staff – measured as the share of researchers with PhD and MSc degrees – improved. In 2000, the share of researchers holding postgraduate degrees was 8 percent higher than one decade earlier, mostly a result of a relative increase in researchers trained to the MSc levels.

Many countries received considerable financial support for training their research staff, often as part of large World Bank projects or through contributions by bilateral donors or agencies such as the Rockefeller Foundation. The education level of agricultural researchers has on average improved during the past decade despite reported high turnovers of staff. Far more researchers have been trained, but never returned to the job or left the agricultural research organizations for better jobs elsewhere. Low remuneration packages are considered a major drawback to retaining and motivating highly qualified staff. When informally asked about the impact of the HIV/AIDS epidemic on staffing, it was often considered a relatively minor issue compared to losing staff for other reasons.

In 2000, 21 percent of the total FTE researchers in a 13-country African sample were female (against 17 percent in 1991), ranging from 16 percent of those holding a PhD degree to 26 percent of those holding a BSc degree as their highest level of education (Figure 5.6) (Roseboom and Beintema, 1996). The relative number of female researchers differs substantially between the various countries.

Total public spending as a percent of agricultural gross domestic product (AGGDP) is a common research investment indicator that helps place a country's agricultural R&D spending in an internationally comparable context. In 2000, the 11 countries in our sample invested US\$0.76 for every US\$100 of AGGDP, which is lower than the 1991 and 1981 levels (Table 5.3). These intensity ratios ranged from just 0.2 for Madagascar and Sudan to 2.6 for Kenya, 3.0 for South Africa and 4.0 for Mauritius. The latter are well above the ratio observed for most developing countries and, in the case of South Africa and Mauritius, are above the average for the developed countries as well (Figure 5.7).

The structure and sources of funding of the principal agricultural research organizations across 12 African countries is surprisingly diverse (Figure 5.8).

The average share of government funding in 2000 was about 60 percent, while donor funding represented 38 percent. The latter is much low-

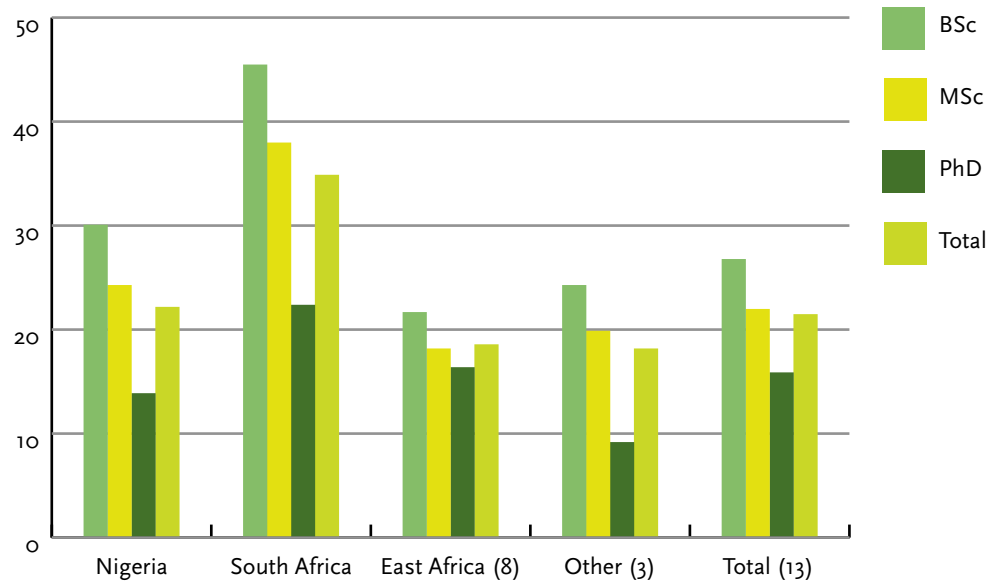


Figure 5.6 Share of female researchers in selected African countries, 2000.

Source: Beintema (2003).

Note: Sample covers the same countries as Table 5.2, except for Côte d'Ivoire.

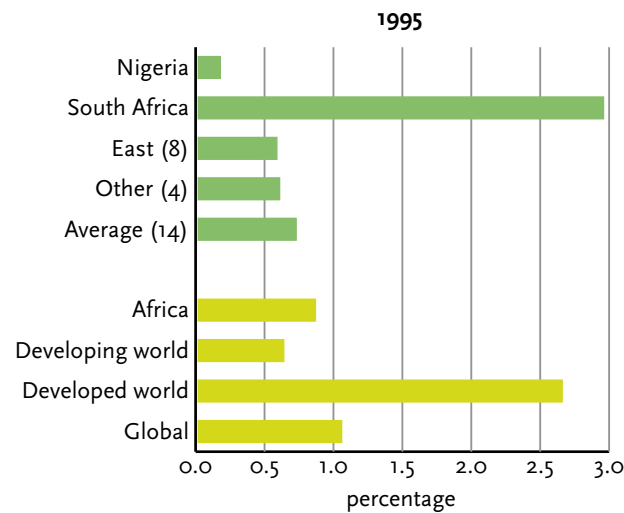


Figure 5.7 Africa's agricultural research intensity compared regionally and globally, 1995. Source: Beintema (2003). Note: See Table 5.2 for country coverage.



Table 5.3 Agricultural R&D intensity ratios in selected African countries for 1981, 1991, and 2000

Country	Total agricultural R&D spending								
	as a share of AgGDP			per capita			per economically active person in agriculture		
	1981	1991	2000	1981	1991	2000	1981	1991	2000
	<i>(percentage)</i>			<i>(1993 international dollars)</i>					
Burundi	na	1.33	0.42	na	5.0	1.1	na	na	2.2
Côte d'Ivoire	1.28	0.99	0.67	7.2	5.0	3.1	27.6	21.6	15.4
Eritrea	—	—	1.68	—	—	2.4	—	—	6.3
Ethiopia	0.19	0.29	0.38	0.6	0.8	1.1	1.5	2.1	3.1
Ghana	0.21	0.46	0.43	1.7	3.2	2.7	6.1	11.5	9.6
Kenya	1.31	1.76	2.55	3.8	4.4	4.3	9.9	11.5	11.0
Madagascar	0.52	0.89	0.19	1.4	2.1	0.5	3.6	5.7	1.3
Mauritius	2.35	2.15	3.96	11.1	12.7	19.4	118.4	191.2	375.4
Sudan	0.64	0.75	0.21	2.4	2.3	1.2	9.0	8.9	4.8
Tanzania	na	na	0.38	na	na	0.7	na	na	1.8
Uganda	na	na	0.50	na	na	2.1	na	na	5.4
Zambia	1.90	2.31	0.35	3.3	3.1	0.6	10.0	9.6	2.1
Subtotal (9 countries)	0.61	0.77	0.57	2.4	2.5	2.0	6.7	7.5	6.3
Nigeria	0.81	0.30	0.38	2.0	0.9	1.0	9.5	5.1	7.4
South Africa	1.47	2.13	3.02	8.8	7.3	7.4	139.7	142.7	184.8
Total (11 countries)	0.85	0.83	0.76	3.2	2.6	2.3	11.9	10.8	10.4

Source: Beintema (2003).

Note: Intensity ratios measure the degree of investment in agricultural research and development as a proportion of various measures of the size of the agricultural sector. Totals and subtotals exclude Burundi, Tanzania and Uganda due to lack of comparable historical data.



er than the 48 percent donor share reported by Pardey and colleagues (1997) for 21 African countries (excluding South Africa) for 1991, and suggests a moderation of the high donor dependency throughout the 1990s. As a result of high donor funding, many of the main agricultural research agencies have invested significantly in their physical infrastructure, equipment, and training of staff (Figure 5.9).

Contrary to the impression the Study Panel gleaned from the consultative workshops, salaries do not seem from these data to represent an unsustainable share of the total expenditure, averaging about 42 percent. This compares favourably with the international advanced research centres of the CGIAR, with a figure of 49 percent in 2002. Hence there would seem to be an adequate availability of total operational funds from these figures, again contrary to the impressions from the consultations. However, as there are fewer international scientists in the international advanced research centres supported by their salary budget, there are far more operating dollars per scientist in the international advanced research centres than in the national agricultural research system. (Generally it appears that salaries represent a much higher share of the national research budget than the total budget. This is because donor funds are largely devoted to non-salary components. Also in recent years there has been a major reduction in salaried support staff in favour of rehiring them on casual wages, which then appear as part of operating expenses.)

In 2000, one-half of the FTE researchers in a 14-country African sample conducted crop research (Figure 5.10a). Research on livestock totaled 18 percent while forestry, fisheries, and natural resources research each accounted for 5 percent. Among the crops, fruits (12 percent) and vegetables and maize (9 percent each) were the main items followed by wheat, sugarcane and cassava (5-6 percent each). The remaining crop researchers (53 percent) focused on a wide variety of other crops (Figure 5.10b).

The 14-country sample analyses are based on Sub-Saharan countries. No similar data are available for the North-Africa region. Box 5.5 describes the North African NARS based on the consultative workshop in Morocco (held jointly with AARINENA in early 2003) that provided the Study Panel with valuable information (Besri, 2004).

Impact of investments

While national statistics in Africa may not reflect much in the way of productivity growth in major commodities, as reflected in Chapter 3, the economic return on past agricultural research investments has been attractive. The apparent contradiction can be explained by the fact that produc-

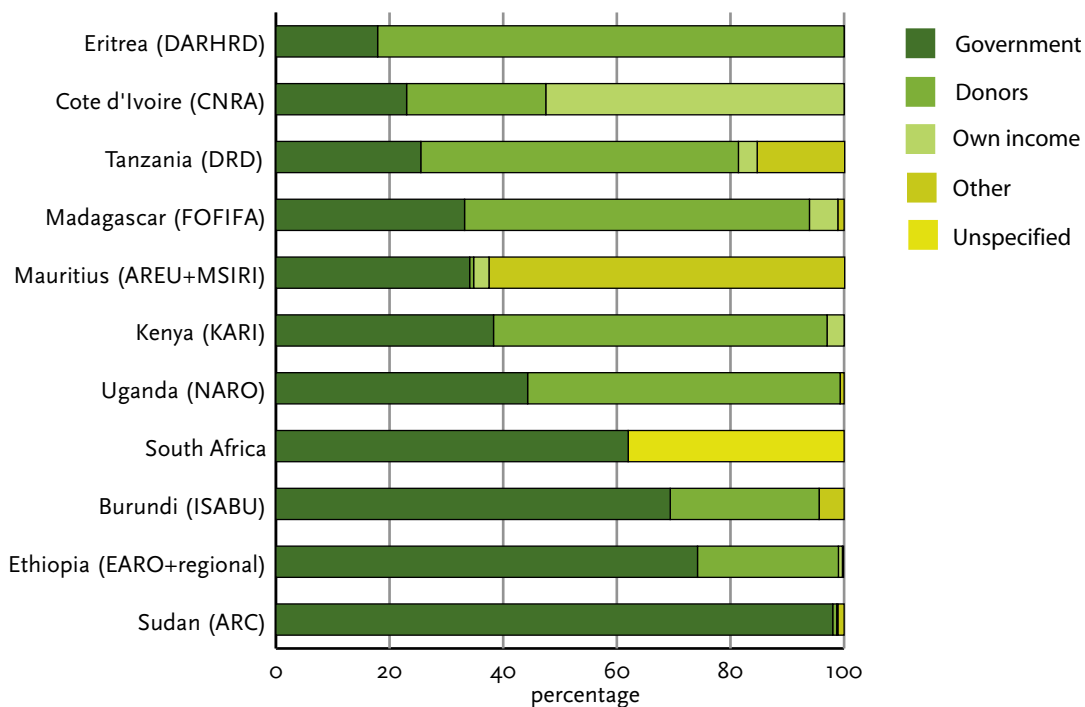


Figure 5.8 Funding sources for national agricultural research in selected African countries, 2000. *Source:* Beintema (2003). *Note:* See individual ASTI country briefs for notes on agency coverage. No breakdown of nongovernment contributions by donor, own income, and other was available for South Africa.

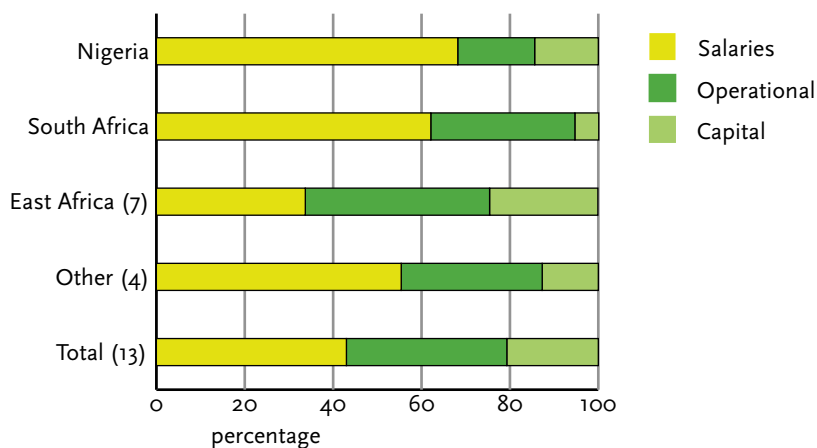
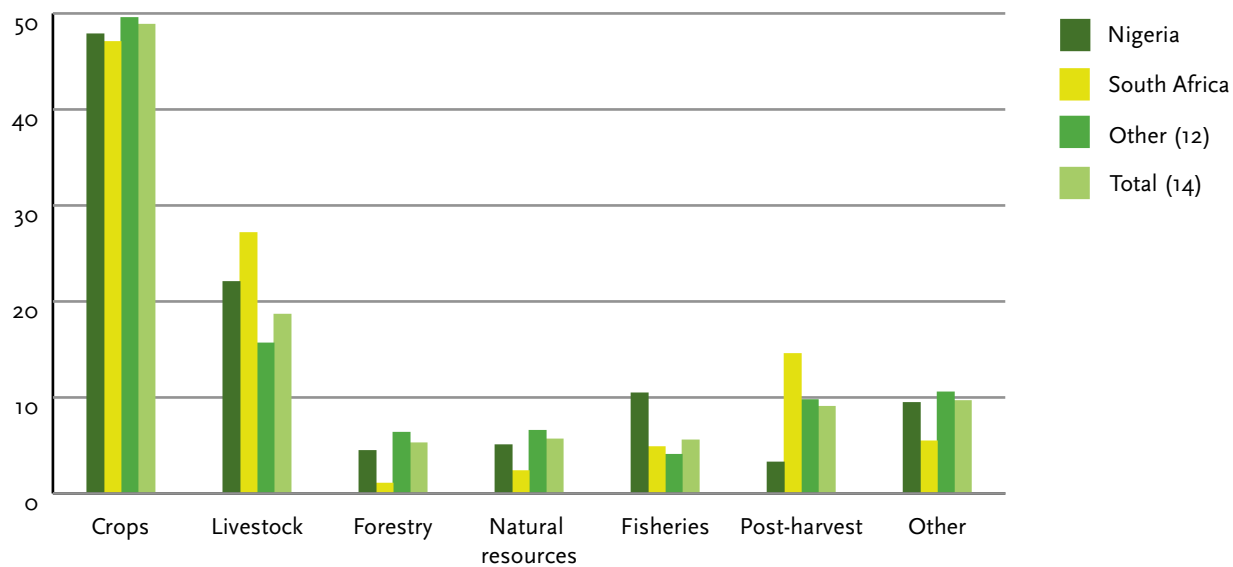


Figure 5.9 Cost-category shares in expenditures for the main agricultural research agencies in selected African countries, 2000. *Source:* Beintema (2003). *Note:* See individual ASTI country briefs for notes on agency coverage. Figure excludes Burundi under 'East Africa'.



A. Full-time equivalent researchers by major program



B. Full-time equivalent crops researchers by item

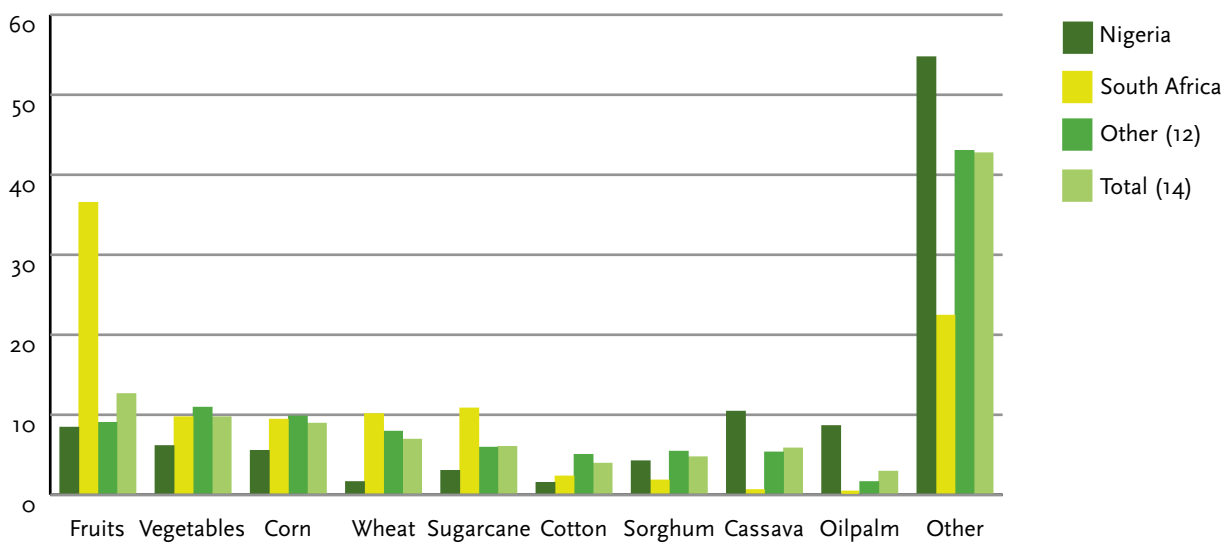


Figure 5.10 A-B Commodity focus of agricultural research expenditures in selected African countries, 2000.

Source: Beintema (2003).

Note: Sample covers the same countries as in Table 5.2, except for Kenya. See individual ASTI country briefs for notes on agency coverage.



tivity would have stagnated or declined at a greater rate than has occurred if it were not for agricultural research investments. This counterfactual is not captured in national statistics. Although somewhat lower than for the other regions in the world, the median rate of return on public agricultural research in Africa from 163 impact studies has been estimated at 36 percent (Table 5.4). This rate is significantly in excess of the opportunity costs of capital (estimated at 12 percent) and very few other public investments command such a high rate of return.

Based on these impressive median or average rates of return, many have argued that there is widespread underinvestment in agricultural research and development, including in Africa. Others, however, have been skepti-

Box 5.5 North African National Agricultural Research Systems

Algeria and Libya rely totally on national resources to support agricultural research, while the other countries have access to significant foreign grants and financial support. Every North African country's proportion of AgGDP allocated to agricultural research is well below the 1 percent recommended for developing countries by international organizations and donors. The research intensities in the early 1990s in North Africa range from 0.25 percent in Algeria to 0.68 in Morocco. By contrast, developed countries typically allocate 2 percent of their AgGDP to agricultural research (Casas et al., 1999).

Some of the current drivers of research in North Africa include:

- Rapid change in technological demand in the region. Water-management issues and the need for export agriculture have increasingly driven the research system, and the market orientation of agriculture has led to greater interest in food-processing quality issues.
- Reorganization of science and technology is taking place, but only slowly. Biotechnology research is important in Egypt, while in other North African countries it is only starting to take off. The region is behind in the use of information and communications technology, though it is felt the further development of information and com-

munications technology capacity will accelerate research organizational changes.

- Changes in interaction between the public and private sectors, with the public sector adopting a facilitator role in favour of private-sector activities. Farmer organizations have greater prominence, regional councils are becoming involved in research policy, and applications based on management and contract research are under way.

Most countries now have specialized institutions in which advanced central infrastructure and expertise are operational, although more capacity building is needed in certain advanced sciences and technologies, such as biotechnology, biosafety, and expert systems. An exception is Egypt, which is strong in these and other areas. There is a great diversity in national agricultural research system in North Africa. In general they are stronger than their counterparts in Sub-Saharan Africa, with more scientists, institutions and universities. Agencies such as the Association of Agricultural Research Institutes in the Near East and North Africa (AARINENA), the Centre International de Hautes Etudes Agronomiques Méditerranéennes (CIH-EAM), the FAO, and the International Centre for Agricultural Research in Dry Areas (ICARDA) are involved in strengthening

the national agricultural research system in the region. The major constraints facing national agricultural research system in North Africa were described as:

- Insufficient investments to keep up with advances in science and technology,
- Insufficient monitoring and impact assessment of research,
- Limited regional coverage of unfavorable agro-ecologies,
- Insufficient incentives to and status of research staff in certain countries,
- Limited regional and international cooperation,
- Limited linkages between research, extension and farmers,
- Low priority to agricultural sciences in university curricula, and
- Weakness of the private sector.

Capacity building of the national agricultural research systems must be a major component of the S&T strategy in North Africa. To have impact on agricultural and national development, such capacity building should cover research policy and planning, research organization and management, international regulatory obligations, technology assessment and transfer, and support for global research partnerships. It was felt that national agricultural research systems of the region can benefit from a regional approach to agricultural research and development.



cal about the rate-of-return evidence and have pointed to two weaknesses: (a) the sample of rate-of-return results is biased towards the success cases and ignores failures; and (b) rate-of-return methodologies are seriously flawed (Roseboom, 2002). Although the defenders of the underinvestment hypothesis tend to share these concerns, they argue that the median or average rate of return is so high that even after adjusting for the various uncertainties the evidence will still hold (Oehmke and Crawford, 1996; Evenson, 2001: 573-628).

An argument frequently put forward in discussions of why the Green Revolution seems to have by-passed Africa is that the diversity in production systems in Africa is many times greater than in irrigated South Asia where the Green Revolution occurred. This gives Asia important economies of scale advantages in the generation and diffusion of new technology. This would explain why Asia has performed better in terms of agricultural (land and labour) productivity than Africa with an on-average lower research intensity ratio. Evenson and Gollin (2001), however, argue that the Green Revolution has not by-passed Africa but that its impact has started later as can be shown by the area cropped under modern varieties across regions and over time (Figure 5.11).

Hence, African farmers have only recently started to benefit from crop genetic improvement. This is consistent with relatively stagnant average yields for most crops across the continent for the past 40 years. Moreover, the increase in agricultural production in Africa has been, until recently, mainly due to the shortening of fallows and the conversion of forests and rangelands into cropland. By bringing poorer land into cultivation and by not allowing cropland to recuperate its fertility (either naturally or artificially), average yields will remain low and the impact of modern varieties will not be evident.

Table 5.4 Rates of return to selected agricultural research projects or programs by geographical region

	Number of observations	Median	Average	Lowest	Highest	Percentage > 20% IRR
Africa total	163	36.3	46.6	-100.0	188.0	77.9
Asia & Pacific	197	51.0	76.4	9.9	526.0	97.0
Latin America & Caribbean	262	42.9	53.2	3.0	325.0	91.2
Developed countries	961	47.4	95.9	-1.3	5645.0	81.4

Source: Alston et al (2000).

Note: Most rate-of-return distributions of agricultural research investments show a wide spread from very low or negative to very high. The distributions tend to be normal, but skewed to the right (i.e., the median < mean); IRR=internal rate of return.



Because in Africa we are dealing with highly diversified, primarily rain-fed agricultural systems – and this will be the case for decades to come – it is likely we will have many smaller ‘green evolutions’ than pervasive Green Revolutions of the South Asian type. In fact the numerous examples now documented in Table 5.4 show there are very high returns to agricultural R&D investments already evident in many individual African research programs and projects. These indicate that there is substantial underinvestment in African agricultural research and development and many more opportunities for profitable investments may be made. Because of its heterogeneity, primary reliance on smallholder rainfed systems, immense size and poor infrastructure, Africa is likely to require greater R&D investments per unit of agricultural productivity improvement than was the case in mostly irrigated South Asian Green Revolution rice-wheat systems. Governments and the international community will have to recognize this and modify their expectations and priorities accordingly.

Increasing research impact

Pleading for more agricultural R&D investment is difficult when the impact evidence of such investments in the recent past seems to suggest that it has been relatively weaker in Africa than elsewhere. Therefore, additional investments in agricultural research in Africa are bounded by the expectation that its impact score will improve substantially. Enhancing the impact of agricultural science and technology is a precondition for mobilizing additional investments in agricultural science and technology in Africa.

There are two processes in particular that, when improved, could help to enhance the impact score of agricultural research, namely (a) priority setting, and (b) monitoring and evaluation. There is broad agreement in the literature that these are crucial processes in the overall governance of agricultural research. Substantial investments have been made during the past 10-20 years to improve priority setting and monitoring and evaluation in African national agricultural research systems, but unfortunately not always very successfully. There is a perpetual effort to improve these processes and adapt them to changing circumstances. As elsewhere, greater stakeholder participation in both processes is seen as an important way forward to enhance the impact of agricultural research. This change in governance of agricultural research is part of a broader development of decentralization and democratization of government that currently is being advocated in quite a number of African countries.

As a complement to increased support for agricultural research and development, institutions and scientists will have to become more account-

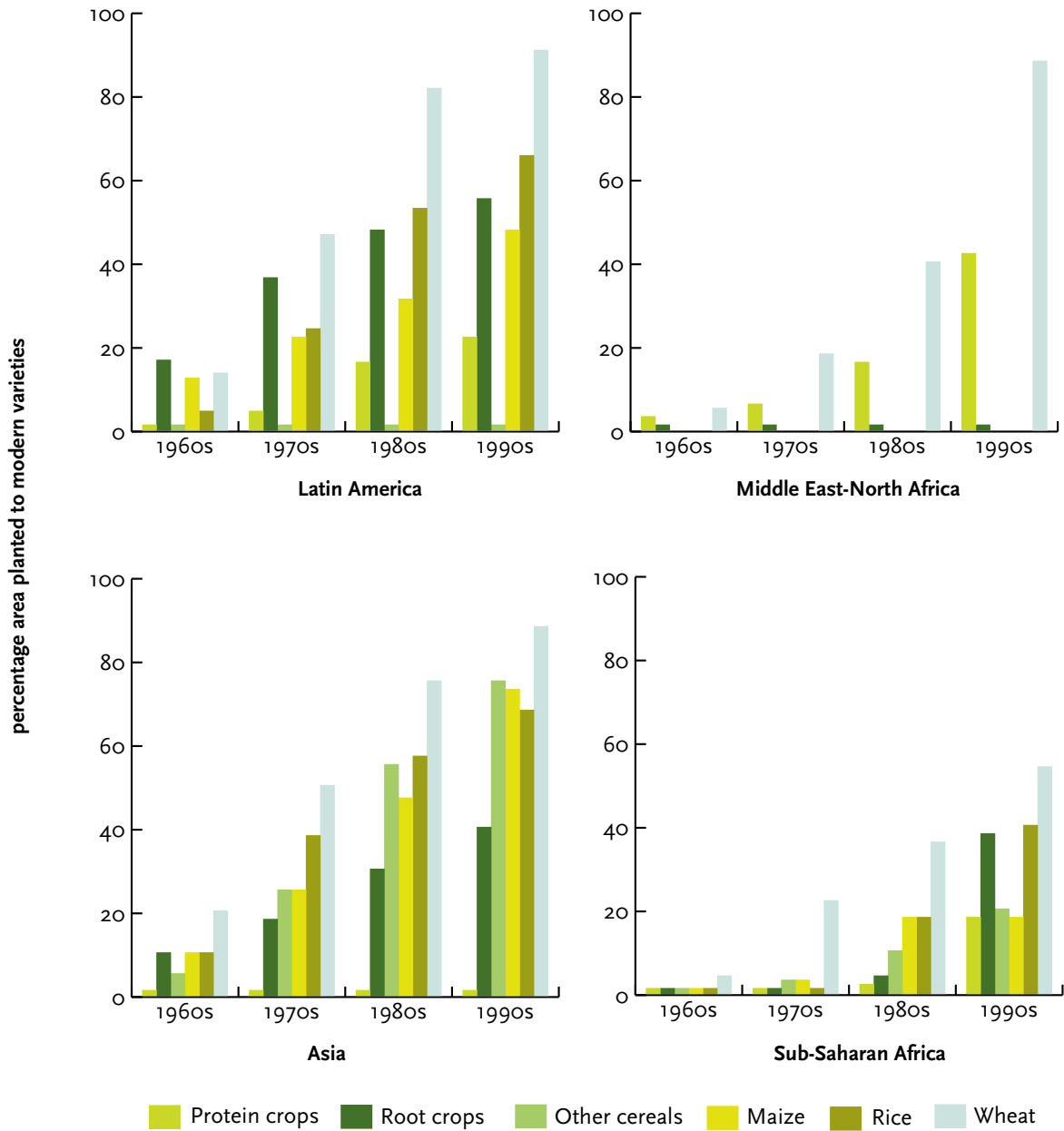


Figure 5.11 Modern variety diffusion by decade and region (percent area planted to modern varieties).
 Source: Evenson and Gollin (2001)



able to society. There must be clear and measurable indicators of success or failure in the strategies and programs that are formulated and funded. These should be used as milestones in an enhanced monitoring and impact evaluation culture. Such indicators need to apply at the level of the institution, but also of the program, department, project and scientist levels. To be effective in building impact-oriented institutions, effective incentive and reward systems need to be introduced that align organizational with individual performance.

Conclusions

Reforms

The guiding principles for African agricultural R&D institutions should be productivity, profitability and sustainability. These principles should apply both to the conduct of the institutions and to programs for smallholders. To quote the former Chairman of FARA, Professor Joseph Mukiibi, in his farewell statement at the FARA Plenary in Dakar Senegal in May 2003, 'Many African farmers and livestock keepers may be poor but they wish to be prosperous. The focus of institutions that serve them therefore must be on prosperity and not poverty. Prosperity-enhancement R&D action programs have to involve the whole production-to-market continuum.'

The Study Panel is of the view that the current NARS reforms are a positive step forward in making agricultural research organizations more client oriented and demand driven, thus potentially enhancing the impact of agricultural research on agricultural productivity. They characteristically now depend on the participation of a broader set of actors, in comparison to the more inward-looking reforms of the 1980s and 1990s.

Involving farmer organizations and other stakeholders more closely in the governance, implementation, monitoring and evaluation of agricultural research requires the building of strong links among these various partners. However, some realism is needed regarding the relative strength of these partners and their ability to participate. The more advanced forms of 'farmer participation' can fail because farmers are not sufficiently organized and because a more client-oriented and demand-driven agricultural research system needs to be matched by clients and stakeholders who can articulate their demand for new technology. International, regional and intergovernmental agencies must play a catalytic role in promoting the reforms proposed here. Research institutions like ISNAR can help inform and guide these developments by action research to synthesize experience into best practice guidelines.



Increased resources

The Study Panel is convinced that Africa deserves a dramatic and sustained increase in the resources devoted to agricultural research and development. It therefore recommends that the expenditure on agricultural research as a proportion of AGGDP rise to at least 1.5 percent by 2015. This would represent a doubling of current average research intensity levels. These added resources should mostly be allocated to strengthening national agricultural research systems. They are below critical mass in key areas, even in the large national agricultural research systems. For the smaller national agricultural research system, strengthening at subregional levels deserves a higher priority. Only strong national agricultural research systems will receive full benefit of complementary activity with the international advanced research centres and advanced research institutions – which should not be viewed as substitutes for national agricultural research systems. The added funding would also provide the support for the evolution of ACARE.

There are also national priorities that will not appear on the agenda of international advanced research centres and advanced research institutions, but still deserve the attention of the national agricultural research systems (e.g., teff in Ethiopia) and ACARE (e.g., game/wildlife). To be sustainable, much of the proposed increase in funding must come from African governments and not from the international donor community. In this respect, the Study Panel is concerned that the World Bank MAPP proposal only calls for 20 percent of the additional funding for African research to be derived from national sources in the first five years, rising to 50 percent in the last five. Donor dependency must cease in agricultural research and the coordination of donor support improved. NEPAD and FARA should play active roles here, with MAPP perhaps providing the vehicle to achieve this. The added resources should be devoted to human resource development. This could include improved conditions of service for scientists, with no more than 60 percent of the budget spent on personnel in order to ensure adequate operating funds and to provide for investments in integrative information and technology infrastructure to enhance connectivity and information exchange.

A doubling of the intensity of the investments in agricultural research as a proportion of AGGDP in Africa towards 2015, as recommended by the Study Panel, would require an annual growth rate of dollar expenditures of around 11 percent. This is a rather ambitious goal for most African countries, compared with their experience during the past 10-20 years (with an



average growth of about 1 percent per annum). However, it is not exceptionally high in comparison to growth rates of agricultural research expenditures in Africa and elsewhere during the 1960s and 1970s (Pardey et al. 1991).

A persistent growth rate of 11 percent annually in agricultural research expenditures may overstretch the absorptive capacity of agricultural research organizations somewhat, but not all of the increase in financial resources should be spent on an expansion of NARS and ACARE research capacities. In many countries, extremely low salary levels inhibit the effective operation of their agricultural research organizations. As an example, if salaries were to double in 12 years within the above 11 percent overall annual funding growth figure, this implies an annual growth in salaries of about 13 percent, while non-salary components would grow by 7 percent per year. This illustrates the scope to achieve both enhanced capacity and new incentive and reward structures.

In general once salaries represent more than half of total research expenditures, scientists become constrained in operating funds for travel, supplies, capital equipment etc. Of course some countries already have research intensities well in excess of 1.5 percent and these average figures obscure the large variability in this measure of research intensity among African countries. Needless to say they also imply many countries have intensities well below 1.5 percent and there is a need to enhance their investments considerably. But as we already noted above, the biggest constraint is how African countries will mobilize this level of resources within their government budgets and from local stakeholder groups.

The CGIAR Centres operating in and for Africa also deserve a substantial increase in their funding if they are to effectively complement the African national agricultural research systems. Their funding should increase by at least 5 percent per year to 2015, reaching an annual total of around US\$235 million.

Experience has shown that the stronger a national agricultural research system, the greater is the benefit the country derives from the research of international agricultural research centres and advanced research institutes. A national agricultural research system can become impact oriented if it is endowed with the following features:

- A *personnel policy* which helps to attract and retain good scientists; such a policy in addition to providing scientists with the best available national salaries, should contain non-monetary but morale-building measures



like linking authority with accountability, as well as facilities like housing, education for children and health care. More will be said about this in Chapter 6.

- *Forward linkages* with government extension, credit and development agencies, as well as with private sector companies dealing with seeds, fertilizers and other essential inputs.
- *Backward linkages* with farm men and women as well as with cooperatives and farmers' organizations through farmer participatory research and knowledge management systems.
- *Lateral linkages* with other R&D institutions, universities, international advanced research centres, advanced research institutions, etc.

For good scientists, salaries alone are not adequate to bring out their best. Social prestige and recognition, and a working atmosphere that values merit and innovation are equally important. Above all, impact-oriented research organizations need visionary leaders whose mission is to bring out the best in staff members. Such leaders should have ready access to ministers and heads of government/state. It would be appropriate to designate the chief scientist heading a national agricultural research system as the Principal Scientific Advisor to Government in the field of agricultural research, education and extension.

Unless the above features are built into the design of a national agricultural research system, its impact will be low and it will neither attract nor retain gifted scientists. Breeding and nurturing good scientists should receive the highest priority from governments, if they are to bring the benefits of modern science and technology to the farming and rural communities.

Scientific communities in Africa are (for the majority of the countries) small and limited in their capacity to generate new information and knowledge. When combined with the weakness of the educational system this represents a serious impediment for the adequate recruitment in numbers and quality of the human capital necessary to tackle the problems of having impact-oriented research, knowledge and development institutions. Governments of countries fitting this description need to understand that they must generate integrated actions in their educational systems before they will find long-term solutions to the problems of capacity building in the agricultural R&D institutions. More will be said about this in Chapter 6.



Recommendations

- ▶ Design and invest in national agricultural science systems that involve farmers in education, research and extension
- ▶ Encourage institutions and mechanisms to articulate science and technology strategies and policies
- ▶ Cultivate African centres of agricultural research excellence
- ▶ Increase support for agricultural research and development
- ▶ Strengthen international agricultural research centres



References

- Alston, J. M., C. Chan-Kang, M. C. Marra, P. G. Pardey, and T. J. Wyatt. 2000. A meta-analysis of rates of return to agricultural R&D. IFPRI research report no. 113. International Food Policy Research Institute. Washington, DC
- Beintema, N. M. 2003. Recent developments in African agricultural R&D investments. Paper presented at the second Forum for Agricultural Research in Africa (FARA) plenary, Dakar, 19-20 May.
- Beintema, N. M., and P.G. Pardey. 2001. Recent developments in the conduct of Latin American agricultural research. Paper prepared for the international conference on agricultural science and technology, Beijing, 7-9 November.
- Beintema, N. M., P. G. Pardey, and J. Roseboom. 1998. Educating agricultural researchers: A review of the role of African universities. Environment and production technology division discussion paper no. 36. International Food Policy Research Institute. Washington, DC
- Besri, M. 2004. Summary, conclusions, and recommendations: North Africa workshop on science and technology strategies for improving agricultural productivity and food security in north Africa. Rabat, Morocco February 3-5, 2003. Hassan II Institute of Agronomy and Veterinary Medicine (IAV HASSAN II), Association of Agricultural Research Institutions in the Near East and North Africa and InterAcademy Council. Accessible at <www.interacademycouncil.net>
- Bonnen, J. T. 1998. Agricultural development: Transforming human capital, technology and institutions. In: Eicher, C. K., and J. M. Staatz. (Eds.) International agricultural development. Third edition. Baltimore, Maryland : Johns Hopkins University Press.
- Brinkerhoff, D. W., J. D. Gage, and S. Gavian. 2002. Sustainable agricultural research systems: Findings and lessons from reforms in Côte d'Ivoire, Ghana, Senegal, Tanzania, and Uganda. Bethesda, Maryland: Abt Associates.
- Bryceson, D. F. 1999. Sub-Saharan Africa betwixt and between: Rural livelihood practices and policies. ASC working paper no. 43. Afrika-Studiecentrum. Leiden.
- Bryceson, D. F. 2000. Rural Africa at the crossroads: Livelihood practices and policies. Natural Resources Perspectives No. 52, <www.odi.org.uk/nrp/52.html>
- Casas, Josephs. (Ed.). 1999. The national agricultural research systems in the west Asia and north Africa region. ICARDA, FAO, AARINENA, CIHEAM. Aleppo, Syria.
- Chema, S., E. Gilbert, and J. Roseboom. 2003. A critical review of key issues and recent experiences in reforming agricultural research in Africa. ISNAR research report no. 24. International Service for National Agricultural Research. The Hague, The Netherlands.
- Chema, S., and J. Roseboom. 2004. Reaching the African smallholder: Are current reforms helping us to get there? Paper presented at the ASARECA/IAC Consultative Workshop for Eastern and Central Africa, Nairobi, Kenya, January 31-February 2, 2003. Accessible at <www.interacademycouncil.net>
- Eicher, C. K. 1999. Institutions and the African farmer. Distinguished Economist Lecture. International Maize and Wheat Improvement Center (CIMMYT). Mexico, D. F.
- Eicher, C. K. 2002. Mozambique: An analysis of the implementation of the extension master plan. Staff paper no. 2002. East Lansing, MI.: Department of Agricultural Economics, Michigan State University. Available at <agecon.lib.umn.edu/msu/sp002-31.pdf >
- Eicher, C. K. 2004. Rebuilding Africa's scientific capacity in food and agriculture. Background Paper No. 4 commissioned by the InterAcademy Council (IAC) Study Panel on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in Africa. Accessible at <www.interacademycouncil.net>



- Elliott, H. E. 2000. Competitive grants in the new millennium: The devil is in the details. In: Reifschneider, F. J. B., D. R. Byerlee, and F. B. de Souza. (Eds.) Competitive grants in the new millennium: A global workshop for designers and practitioners. Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA)/Inter-American Development Bank (IDB)/World Bank. Brasilia, Brazil.
- Evenson, R. E. 2001. Economic impacts of agricultural research and extension. In: Gardner, B. L., and G. C. Rausser. (Eds.) Handbook of agricultural economics. Amsterdam: North Holland/Elsevier.
- Evenson, R. E. and D. Gollin. 2001. The green revolution at the end of the twentieth century. Paper prepared for IAC's standing panel on impact assessment. Technical Advisory Committee Secretariat, Food and Agriculture Organization. Rome.
- FAO (Food and Agriculture Organization) and the World Bank 2000. Agricultural knowledge and information system for rural development (AKIS/RD): Strategic vision and guiding principles. Rome.
- Gautam, M. 1999. World bank agricultural extension projects in Kenya. Impact evaluation report no. 19523. World Bank. Washington, DC
- Gemo, H., C. K. Eicher, and Solomon Teclmariam. 2003. Mozambique's experience in building a national agricultural extension system, 1987-2003. Maputo: DNER, MADER. July draft.
- Gill, G. J., and Carney, D. 1999. Competitive agricultural technology funds in developing countries. Overseas Development Institute (ODI). London.
- Haug, R. 1999. Some leading issues in international agricultural extension, a literature review. *The Journal of Agricultural Education and Extension*, 5(4): 263-274.
- Hambly, H., and L. Setshwaelo. 1997. Agricultural research plans in Sub-Saharan Africa: A status report. ISNAR research report II. International Service for National Agricultural Research. The Hague, The Netherlands.
- Hussi, P., J. Murphy, O. Lindberg, and L. Brennenman. 1993. The development of cooperatives and other rural organizations: The role of the world bank. World Bank. Washington, DC
- IAC (InterAcademy Council). 2004. Inventing a better future: A strategy for building worldwide capacities in science and technology. Amsterdam: InterAcademy Council. Accessible at <www.interacademycouncil.net>
- Kangasniemi, J. 2002. Financing agricultural research by producers' organizations in Africa. In: Byerlee, D., and R.G. Echeverría. (Eds.) Agricultural research policy in an era of privatization. Wallingford, U.K.: CAB International.
- Michelsen, H., L. Zuidema, C. Hoste, and D. Shapiro. 2003. Improving agricultural research at universities in Sub-Saharan Africa: A study guide. Research management guidelines no. 6. International Service for National Agricultural Research. The Hague, The Netherlands.
- Nahdy, S., F. Byekwaso, and Nielson, D. 2002. Decentralized farmer-owned extension in Uganda. In: Breth, S. (Ed.) Food security in a changing Africa. Centre for Applied Studies in International Negotiations. Geneva.
- NEPAD (New Partnership for African Development). 2002. Comprehensive Africa agriculture development programme (CAADP). New Partnership for African Development (NEPAD). Midrand, South Africa.
- OECD (Organisation for Economic Co-operation and Development). 1994. The measurement of scientific and technical activities 1993: Standard practice for surveys of research and experimental development. Frascati Manual. OECD. Paris.
- Oehmke, J. F., and E. W. Crawford. 1996. The impact of agricultural technology in sub-Saharan Africa. *Journal of African Economies*, 5(2): 271-292.



- Pardey, P. G., J. Roseboom, and J.R. Anderson. (Eds.) 1991. *Agricultural research policy: International quantitative perspectives*. Cambridge: Cambridge University Press.
- Pardey, P. G., J. Roseboom, and N. M. Beintema. 1997. Investments in African agricultural research. *World Development*, 25(3): 409-423.
- Pardey, P. G., and N. M. Beintema. 2001. *Slow magic: Agricultural R&D a century after Mendel*. IFPRI food policy report. International Food Policy Research Institute. Washington, DC
- Röling, N. 1988. *Extension science: Information systems in agricultural development*. Cambridge: Cambridge University Press.
- Roseboom, J., and N. M. Beintema. 1996. Taking count: Female agricultural researchers in Sub-Saharan Africa. *CG Gender Lens*, Vol. 1, No. 1 (July): 8.
- Roseboom, J., P. G. Pardey, and N. M. Beintema. 1998. The changing organizational basis of African agricultural research. ISNAR discussion paper 98-17. International Service for National Agricultural Research. The Hague, The Netherlands.
- Roseboom, J. 2002. Underinvestment in agricultural R&D revisited. *Quarterly Journal of International Agriculture*, 41(4): 297-316.
- Roseboom, J., N. Beintema, and S. Mitra. 2004. Building impact-oriented R&D institutions. Background Paper No. 3, commissioned by the InterAcademy Council (IAC) Study Panel on Science and Technology Strategies for Improving Agricultural Productivity and Food Security in Africa. InterAcademy Council, Amsterdam. Accessible at <www.interacademycouncil.net>
- SPAAR/FARA (Special Program for African Agricultural Research/Forum for Agricultural Research in Africa). 1999. *Vision of African agricultural research and development*. SPAAR. The World Bank. Washington, DC
- UNESCO (United Nations Educational, Scientific and Cultural Organization) 1984. *Manual for statistics on scientific and technological activities*. UNESCO Division of Statistics on Science and Technology. Paris. Processed.
- UNESCO. 1998. *World science report*. Paris: UNESCO.
- Venkatesan, V. 1991. World Bank's agricultural services initiative in Africa: Main issues and future strategy. *Journal of Extension Systems*, December: 28-43.
- Willett, A. 1998. *Agricultural education review: Support for agricultural education in the bank and by other donors (Executive summary)*. World Bank. Washington, DC



6. Creating and retaining a new generation of agricultural scientists

Great strides have been made in increasing the number of universities in Africa and students enrolled in them at all levels, but universities throughout the continent are facing severe financial problems coupled with a decline in the quality of the educational experience. At the same time there has been an exodus of senior academics to nongovernment organizations (NGOs), to the private sector and to attractive international positions (Lynam and Blackie, 1994). The brain drain, especially of associate and full professors, has been especially crippling for many African universities that are trying to build MSc and PhD programs. Senior scholars are needed to set both the research direction and the intellectual tone for their departments, and they are ultimately responsible for the mentoring of postgraduate students and the overall quality of local MSc and PhD programs.

The first generation of post-independence African agriculturalists performed yeoman service starting in the 1960s. They helped launch new universities and faculties of agriculture and tackled research on food crops and livestock for smallholders – both neglected areas of research in colonial export-oriented research stations. In 1960 at independence, roughly 10 percent of the agricultural researchers in Africa were African with the balance being expatriates. Thirty years later 90 percent were African (Beintema et al., 1998) – an impressive achievement by African universities with assistance through a generous flow of scholarships for overseas MSc and PhD training programs.

But now the first generation of African agriculturalists has by and large retired, and their successors – what might be called the second generation of researchers and teachers – have become demoralized by poor conditions of service and the low return rate from overseas of many young academics. This chapter describes the educational challenges facing Africa, with a primary on Sub-Saharan Africa.

Science education

In African schools, science education tends to be particularly weak. At both primary and secondary school levels, science is given little emphasis. Most schools lack even rudimentary libraries and science laboratories, access to



computers is unheard of, and most teachers have little if any science training. As a result, only a small share of secondary school graduates that go on to universities opt for training in the sciences, and those that do are poorly prepared.

There also appears to be strong gender bias in science training. Young women are generally not encouraged to focus on science – particularly biology and agricultural science – in primary and secondary school, with the result that African female participation rates in the agricultural sciences in universities are roughly half of those in other fields (13.8 percent compared to 25.5 percent). Not surprisingly, a survey in 1998 by the United Nations Educational, Scientific and Cultural Organization (UNESCO) of 19 universities found that only 8 percent of agricultural faculty members were women. In many European countries this figure exceeds 50 percent.

Low investment

The facts listed above reflect a more general pattern of low investment in research and development in Africa. Insufficient resources are only part of the problem. Because education in poor countries is less affordable, much clearer educational priorities must be defined, in terms of fields, levels (primary versus secondary versus higher education), quantity and quality. The hard choices surrounding the debate over quantity and quality are especially difficult for contemporary universities in Sub-Saharan Africa, because new universities are being created yet the quality of higher education has fallen.

Without question, the crisis in the African university and research community is severe and is not amenable to a quick fix. African scholars and researchers are currently ill prepared to train the third generation of agricultural scientists starting around 2010. Unless the current crisis in the African scientific community is solved, Africa's next generation of students will be caught in a downward spiral, and the 'scientific divide' between the bio-tech North and the lagging South will widen further.

Growth in student numbers

Between 1960 and 1996, the number of universities in Africa increased from less than 20 to nearly 160. Student numbers grew by 8 percent per year, from 119,000 to almost 2 million over the same period. Funding of higher education generally matched the expanded number of universities and students during the 1960s and 1970s, but has fallen well below growth in student numbers since the early 1980s. The expansion phase of



the 1960s and 1970s was followed by a retrenchment phase in the 1980s and a renewal phase in the early 1990s.

Funding decline

The university expansion phase from the 1960s to the mid-1980s was followed by a retrenchment of domestic and donor support to agriculture and to universities. Fiscal constraints since the mid-1980s accentuated by structural adjustment reforms and a shifting emphasis on primary and secondary education (as part of the 'basic human needs' approach) caused domestic funding for universities to stall and in some cases decline. Real spending per university student declined from us\$6,300 in 1980 to us\$1,500 in 1988 (Beintema et al., 1998). The number of books per student fell from 49 in 1979 to only 7 in 1988 (by way of comparison, the average number in U.S. universities is 78). During the same period, real faculty salaries fell by 30 percent and have continued to decline in most countries. In Nigeria, for example, university faculty salaries in 1991 were only 10 percent of their levels in 1978.

At the same time donor funding was curtailed for students studying agriculture in the northern universities, a trend that continued into the 1990s. For example, United States Agency for International Development (USAID) postgraduate scholarships for developing-country students to study agriculture in the United States fell from 310 in 1990 to only 82 in 2000 (BIFAD, 2003). During the late 1980s and into the 1990s, numerous critics argued for downsizing of African universities. They also proposed that students should pay fees and universities should become more entrepreneurial to gain funding from the private sector (Saint, 1992).

The critics also pointed out that the annual cost of higher education per student was substantially more in Africa than in Asia or Latin America. This led to intense political and policy debates throughout Africa on how to reduce the unit public cost of higher education (Birdsall, 1996). Critics cited a study by World Bank economist George Psacharopoulos (1994) that showed primary education in Africa generated a higher social rate of return to society than secondary and higher education. In short, during the 1990s African universities experienced a fall from grace, both at home and among donors (Saint, 1992).

Renewal

The period of retrenchment and decline in funding in the late 1980s and 1990s was followed by an unexpected renewal phase initiated by a half



dozen African universities. University reforms included the admission of private fee-paying students, permission for faculty members to retain a share of incomes generated from private consulting income, the introduction of night classes and private universities, and the adoption of information and communications technology (ICT) for class work and university administration (Court, 1999).

But these reforms did not take place in a vacuum. Rather they were a product of larger political and social reforms. Uganda and Kenya are prime examples, where new leadership is propelling a democratic transition in the State House and beyond (Lynam, 2003). For example at Makerere University in Uganda the Innovation at Makerere program, better known as I@mak.org, is reorganizing its academic programs to contribute directly and immediately to national development within the framework of the government's decentralization process. It aims to train cohorts of public servants in health, agriculture and administration, to staff district offices. It is achieving this through major changes in curriculum and through 'sandwich training' programs whereby students undertake fieldwork in the districts throughout their academic training.

In response, many donors have rediscovered universities. The World Bank is a prime example. For several decades the Bank has given priority to investments in primary education, but its new leadership in human resources has warmly embraced investments in higher education, outlined in its new book *Constructing Knowledge Societies: New Challenges for Tertiary Education* (World Bank, 2002). Finally, a new USAID global initiative has recently been introduced to increase the number of scholarships for post-graduate study in agriculture in the United States and capacity-building grants to rebuild university faculties of agriculture in developing countries (BIFAD, 2003).

Four U.S. foundations have played a critical role in supporting the renewal phase of African higher education. In 2000, the Rockefeller, Ford, Carnegie and MacArthur Foundations launched *The Partnership for Higher Education in Africa*. With a 10-year time frame, the foundations have committed us\$100 million over the first five years to support universities pursuing reforms in Ghana, Mozambique, Nigeria, South Africa, Tanzania and Uganda. During the first two years (2000-01), the four foundations together contributed us\$62 million to higher education in six African countries.



Linking scientists in universities and national agricultural research institutes

Changes described above have occurred during a period in which parallel efforts were under way to link university academic staff (with advanced degrees) with scientists in national agricultural research institutes to work together on problems of mutual interest (Michelsen et al., 2003). This has arisen because universities often have more PhDs in agriculture than the government research system – in 1995, for example, universities employed around 550 African scientists with PhDs in agriculture while the national agricultural research systems (NARS) in Eastern and Southern Africa employed around 360 (Mrema, 1997).

Despite their numbers, university-based scientists conduct a minor share of public research – in 1991 universities reported only 10 percent of public agricultural research and development (R&D), compared with 43 percent in Organization for Economic Co-operation and Development (OECD) countries; and a majority of African faculties spend less than 20 percent of their time on research (Beintema et al., 1998). The universities have desire as well as a latent potential to become major players in agricultural research and development if the appropriate incentive and reward systems are created to attract and retain young academics.

In order to increase the ability of university scholars to carry out research, Competitive Grant Schemes are now in operation in World Bank-financed projects in countries such as Ghana, Kenya and Malawi (Echeverria and Elliott, 2002). However, these funding schemes are often oversold and they are difficult to administer in small countries. There have also been many problems in the NARS-university relationship: conflict and misunderstanding are commonly reported between the strong (NARS) and the weak (faculties of agriculture) (Castillo, 1997). An African professor recently summed up the NARS-university relationship as follows, ‘At present, academics and NARS staff view each other as competitors.’

Setting up African-based graduate programs

Undergraduate education is the bread-and-butter of African university education, and the political pressure to open new universities and increase undergraduate enrollment is relentless. African-based graduate programs have been neglected; for instance, as few as 20 Africans a year currently receive doctorates in economics, from both within and outside the continent (including South Africa) (Fine, 1997). There has also been a sharp reduction in the number of scholarships for Africans to study agriculture overseas.



This explains one reason why the African Economic Research Consortium (AERC) was launched in 1988. When the AERC carried out a study of graduate education in economics in Africa, it found that ‘graduate training in any meaningful sense appeared to have collapsed in most African universities’ because of the ‘lack of funds, civil disorder, loss of good staff, deteriorating faculties and equipment, and a massive expansion of undergraduate enrollment’ (Fine, 1997).

Many donors have eliminated or greatly reduced support to overseas graduate training, citing high costs, questionable relevance to Africa’s immediate development problems and low returnee rates. The donors have thereby accelerated the transition to graduate training in Africa. Many African educators and donors have called for African-led initiatives to experiment with new models of postgraduate training that will allow African countries to build sustainable linkages to overseas universities at lower cost. Table 6.1 displays the comparative cost of MSc and PhD degrees in various universities around the world.

Special efforts are needed to shore up the quality of MSc degree programs within Africa because local training has many advantages above overseas training. First, the course work in local degree programs is likely to better prepare students for careers in agricultural extension because the courses are grounded in national agricultural policies and local agro-ecologies, institutions and farming systems. Second, students in local MSc and PhD programs are more likely to focus their research on local and national problems than students in overseas universities. Third, the incremental build-up of the quality of local graduate programs will serve as an insurance policy if a donor discontinues offering scholarships for overseas study. These direct and indirect benefits of local graduate training should be factored into comparative studies of the costs and benefits of local versus regional and overseas training.

However, the Africanization of graduate education is occurring precisely when the quality of undergraduate education in Africa is declining, due to the rapid proliferation of faculties of agriculture and forestry and a total loss of capacity for some fields (especially agricultural economics and economics) to offer high-quality MSc degree programs. African students pursuing MSc degrees in African universities often take 4-5 years to complete a two-year MSc degree due to problems in finding thesis supervisors who will mentor and nurture the students and read draft manuscripts on schedule as promised.



Table 6.1 Comparative cost of graduate degrees in agriculture in various universities

Degree	Years for degree	University	Estimated total cost (US\$)	Year
MSc	2	U.S. universities	56,000	2003 (incl. out-of-state tuition)
MSc	2	Australian universities	32,000	1998
MSc.	2	Southern African universities	31,000 ^a	1998
MSc	2.5	Makerere University, Uganda	25,000	1998
MSc	2	UPLB, Philippines	24,000	1998
MSc	2	University of Malawi	18,000	1997
PhD	3	U.S. universities	90,000	2003 (incl. out-of-state tuition)
PhD	3	Asian Inst. of Technology (Bangkok)	40,000	2003 ^b
PhD	3	Univ. Agriculture, Bangalore (India)	23,000	2003 ^b
PhD	3	University of Natal	55,000	2003
PhD	4	Belgium universities ^c	35,000	2003

^a Total cost per MSc degree in four specializations (agronomy, animal science, land and water management and agricultural economics) in four universities in Southern Africa (Anandajayasekeram et al., 1996)

^b Suvedi (2003)

^c Tollens (2003). Four-year sandwich/fellowship program; the student spends one-third time in Belgium and two-thirds overseas.

Regional approaches to graduate training

The pressures described above have led to renewed interest in regional approaches for graduate training. The establishment of regional centers of excellence or regional specializations in undergraduate or graduate programs has been debated for decades, and the experience has been mixed. There are potential efficiencies in assembling a critical mass of specialists in particular academic domains in one location that could serve the graduate training needs of a larger regional watershed. Regional training programs are frequently mentioned as a way to drive down the unit cost of graduate programs, but it is generally recognized that building another new layer of educational institutions can be risky, divisive and expensive. Ideally they should evolve from existing strong national institutions and not be created de novo.

The University of Nairobi launched an MSc program in agricultural economics in 1974 for students from East Africa, with financial assistance from the government of Germany (Thimm, 1992). The two-year program consisted of coursework during the first year and thesis research in the student's home country during the second year. The program flourished



during the 1970s, but low salaries, funding constraints and frequent university closures led to the loss of eight staff members with PhDs between 1985 and 1995 from the Agricultural Economics Department in Nairobi. Student numbers fell to three (all Kenyan) in 1997 due to the lack of scholarships. This sobering case study of a 25-year effort (1974-99) to build and sustain an MSc degree program reveals that it may be easy to garner foreign aid to launch a regional MSc program but it is difficult to gain local political and financial support to sustain it decade after decade (Oniangio and Eicher, 1998).

Seasoned observers have made a strong case for self-initiated efforts to build 'regional specializations' in existing universities and then develop networked training programs, instead of creating new regional centers of excellence. As described in Chapter 5, the Study Panel believes that this evolutionary approach to the formation of African centres for agricultural research excellence (ACARE) is the preferred pathway for this institutional innovation. Examples include the newly launched PhD Plant Breeding Program at the University of Natal, the MSc in Agricultural Extension at Makerere University in Uganda, and the MSc in Natural Resource Management at the University of Pretoria, all of which receive some support from the Rockefeller Foundation. Experience suggests however that if these are to succeed they must first have adequate external support for design, launch and fine-tuning, but to be sustained they must generate national or regional resources. They must be intellectually competitive with global training alternatives, have strong buy-in and commitment for regional cooperation from a critical mass of partner universities, and undertake business in a fully transparent and accountable manner.

Sandwich training and other innovations

A number of universities in Europe such as Wageningen University and Research Centre, have pioneered the sandwich training model as a means of lowering costs and increasing the returnee rate. This approach allows African PhD students to take a year of postgraduate course preparation at their home university and then go overseas for 12-18 months to pursue further course work and return home for thesis research. The student and local co-supervisor travel between the home country and Wageningen as required during the four-year program. This has the advantage of allowing the student to focus on national priorities while building capacity and decreasing the chances of a brain drain. Further examples of sandwich programs in Africa are provided in the first InterAcademy Council (IAC) report (IAC 2004: 52-53).



There are some drawbacks. Supervisors may want students in their labs for two to three years of concentrated work, and it may be difficult and time-consuming for co-supervisors to visit a student in the field. But it has worked well at Wageningen University and Research Centre, which over the past five years has had more than 200 MSc and at least 50 PhD graduates from Africa. Many have gone into senior positions in government and universities in their home countries.

In addition to cost-cutting sandwich training models there are other innovations to reduce the cost of postgraduate training. These include increased use of distance education and information and communications technology and summer institutes; and encouragement for students to form human capital chains via the Internet – an effective way to remain in contact with their thesis supervisors and gain ready access to the global scientific literature. Here again the recent IAC report has insightful suggestions for virtual networks, digital libraries and the like (IAC, 2004: 59-60, 66-68)

Joint appointments of recent PhD graduates for a few years after graduation at their home university and Wageningen offer mutual advantages of continuing professional linkages and development. Interchange programs of post-doctoral fellows with a variety of foreign universities and local ones have proven to have impact, both from the view point of intellectual gains as well as of the establishment of long-term academic relations once the visiting post-doctoral staff return to their respective institutions.

There is also high value in twinning and mentoring arrangements between faculty from a developed country and African universities. This is also desirable between the stronger African universities and those less strong. By institutions sharing their strengths and receiving help where they themselves are not so strong, the quality of training can be improved. This cooperation would also be effective in raising morale and retaining staff as it removes professional isolation and the feeling of belonging to an institution that delivers inferior products. Perhaps by working with New Partnerships for Africa's Development (NEPAD), the Forum for Agricultural Research in Africa (FARA), the Consultative Group on International Agricultural Research (CGIAR), subregional organizations and advanced research institutes, the IAC could develop and maintain databases to facilitate the identification of North-South and South-South partners in such collaboration, with the associated benefits of pooling resources. The IAC (2004: 54-58) has some encouraging examples where such programs are working in other fields.



Harnessing information and communications technologies

One of the greatest handicaps for African scientists and educators is their remoteness from global sources of scientific literature. To conduct research efficiently, scientists need current access to information on recent discoveries and methods. University professors, staff and students need access to recent peer-reviewed literature to align curricula with world standards and to write quality research proposals and reports. Due to such difficulties, African faculty has been isolated from the international academic community, with adverse effects such as inbreeding.

Unfortunately, access to such useful information in most African countries is limited. Much of the agricultural science literature is found in several hundred international peer reviewed journals that are prohibitively expensive. As a result, students graduate from many African universities without knowledge of the most recent findings and methods in their fields, also scientists design research that repeats earlier work or they use outdated and inefficient methods. The revolution in genomics has created a wealth of useful information that is relevant for crop improvement worldwide, but this is scattered over many diverse, usually web-based, databases that often require high-speed access and are difficult to interpret.

Accelerating developments in information and communications technology hold the promise of integrated global systems that provide rapid and low-cost access to information by anyone anywhere in the world. This can provide opportunities to develop new models for postgraduate education. This could include encouragement of private investment in agricultural higher education, including virtual and open universities, as is being explored by the CGIAR and its partners in Africa. But the digital divide, often reinforced by inappropriate policies and regulations of African countries themselves, contributes to an information apartheid that separates most developed countries from many developing ones.

Several initiatives have already been launched to enhance developing-country access to such information. In 1997, with Rockefeller Foundation support, Cornell University built The Essential Electronic Agricultural Library (TEEAL), consisting of CD-ROMS that contain the full text of 140 key agricultural and life science journals. The TEEAL is currently used at 62 institutions in 32 developing countries, including 41 institutions in Africa. The Rockefeller Foundation, Food and Agriculture Organization (FAO), World Health Organization (WHO), CGIAR and Cornell University are now working together with major publishers to design an on-line platform, similar to the Health InterNetwork Access to Research Initiative (HINARI), for free



access to a comprehensive collection of agricultural and food security journals. The initiative has been christened Access to Global On-line Research in Agriculture (AGORA).

Without question, there is significant potential for web-based distance education to both complement and supplement courses given in African universities. A number of us universities are offering courses and degrees over the Internet. However, this is not yet a proven model for granting degrees in most African countries. Graham Till (2003) in his recent review of information and communications technology in Africa wrote:

There has come to be a simplistic but widely held notion that information and communications technology will automatically benefit African education. The reality, however, is that information and communications technology can't go it alone: quality assurance, provided by adequate human resource infrastructure, is an essential part of the equation. Regrettably, such infrastructure is presently inadequate to meet the demand for post-secondary entry to higher education across the region in most of Africa.

The World Bank financed establishment of the African Virtual University (AVU) in 1997 to provide quality higher education in science and engineering. The AVU has offered courses but does not yet offer full degree programs. The Institute for Food Laws and Regulations at Michigan State University has created six distance education courses on food laws and regulations, which are only US\$794 per course. USAID's dot.com initiative and the investment of other donors will add substantially to the information and communications technology infrastructure of developing countries. As this infrastructure grows, there will be more opportunities to test the benefits of providing education electronically.

Another recent ICT application is providing lectures and seminars via teleconference. Now African students can hear, and indeed interact with, global leaders in their fields while remaining in their home settings. Cornell University professors now provide lectures on cutting-edge topics in breeding and biotechnology to students participating in a regional PhD program offered by the University of Natal, with support from The Rockefeller Foundation. There is scope to enlist more support from private sector ICT companies in these type of initiatives.



Halting the 'brain drain'

Graduate education in developed-country universities provides an opportunity for young Africans to connect with world-class institutions and faculties, to work in well-equipped libraries and laboratories and to establish professional networks with global reach and career-long impact. But such opportunities also establish bridges that draw trained Africans to employment out of Africa. The magnitude and potential impacts of those flows are substantial and appear to be increasing over time.

It is estimated that during 1960-1974 approximately 1,800 skilled Africans emigrated annually in search of foreign employment opportunities (Saint, 1992). This rose to 4,400 from 1975 to 1984 and further to approximately 23,000 in 1987. The United Nations Conference on Trade and Development (UNCTAD) estimates that approximately 30 percent of all highly trained Africans currently reside outside Africa.

The starting point for any situational analysis is to acknowledge that there is a global market for advanced human capital-financial incentives, professional satisfaction, and opportunities to be scientifically productive are central to the migration of talent. Carl Eicher (2003) has observed from 40 years of work in Africa that once African nations experience a major exodus of 10,000 or more scientists, managers and teachers following a civil war, coup d'etat or decades of economic stagnation (as has occurred in Ethiopia, Ghana, Nigeria, and Somalia), it is very difficult to attract any substantial number to return home while their country of birth remains at a low-income status.

History adds a valuable perspective on the relationship between post-graduate training and incentives, the brain drain and capacity building in developing countries. Successful institution-building experience in Brazil, Chile, China, India and Malaysia over the past 30 years enabled these countries to attract young scientists on overseas graduate training programs back home to pursue careers in the core agricultural institutions and the private sector. They were drawn by a scientific infrastructure that included post-degree networking, mentoring, access to the global scientific literature, availability of competitive research grants, sabbatical leave and participation in on-going national and regional workshops on development policy, management and research topics (BIFAD, 2003).

Buoyed by the success of India and China in enticing nationals to return home permanently to pursue scientific and managerial positions, a number of observers have posed the question: Can senior African agricultural professionals be encouraged to return to Africa and help fill the human



capital gap? In short, can Africa regain its scientists? The sharp cutback in long-term technical assistance from the North in the 1980s has been followed by a number of innovative programs through which professional members of the African Diaspora take consultancies providing short-term technical assistance in Africa. One such initiative is TOKTEN (Transfer of Knowledge Through Expatriate Nationals), a project of the United Nations Development Programme. This has had limited success as it evokes more envy on the part of erstwhile colleagues rather than a desire to emulate.

A number of African scientists have organized global networks to mobilize African scientists living overseas to return to their home university and offer short courses and help mobilize funds. For example, Ethiopia has developed a global network of Ethiopian scholars who are living in the Diaspora (GNEST, 2003). Likewise, Friends of Njala University College in Sierra Leone is a network of Africans and non-Africans who are helping to rebuild the scientific infrastructure at Njala. But these are primarily short-term assignments and do not achieve a full recapture of human capital lost to the brain drain.

It seems clear the only effective and sustainable approach is to make agricultural science and agribusiness more personally and professionally attractive, and indeed more closely competitive with global opportunities. It is more realistic to lure back young African scientists rather than to expect senior academics and researchers to leave the Diaspora and return permanently to Africa. It is even more desirable to focus instead on preventing the next generation of scientists from migrating in search of a more professionally and personally rewarding career. But both political and scientific leadership are needed to support the development of an attractive package of monetary and non-monetary incentives to encourage young scientists to remain home. Start-up research grants and rapid career advancement are key components of a strategy to prevent future brain drain. Can this be done in Africa? Case studies in Brazil, China, Malaysia and more recently in Mozambique suggest that it is possible if there is political commitment to agriculture, adequate resources and imagination.

In the consultative workshops, the Study Panel heard pleas from scientists for greater recognition and encouragement of their profession by the community and governments. There was a sense in which they viewed the enhanced prestige this would generate as equal to, if not more important than, increasingly attractive financial rewards, in order for scientists to fully express their own potentials and contribute to Africa's development.



Curricula

The major challenge facing African countries now is how to meet the growing demand for tertiary education while simultaneously improving quality and relevance within shrinking public budgets. Demand for the cadre of highly specialized graduates has waned. And the emerging trend – the staged approach of producing 'Boabob' graduates as is currently the practice in Francophone West and Central Africa – is to provide common, post high school training in biological, social and technical sciences, and thereafter allow student participation in the learning process through internships, applied research projects, direct involvement in agricultural production and processing experience in community development.

An important aspect, especially in the research component of training, is to emphasize inter-disciplinary and participatory research approaches that address the problems and opportunities of rural communities and integrate indigenous knowledge with modern science. Scientists, while pressing for greater social recognition and reward, need to be more impact oriented and concerned with the use of their research findings for broader societal gains and the needs, aspirations and priorities of producers, markets and industry rather than settling for the appearance of their research findings in scientific publications.

The universities need to produce graduates (scientists) with strong moral values and ethics, a commitment to social and environmental justice and a capability to develop and implement new ideas and to generate rather than seek employment. Agricultural education needs to move away from mere transfer of information to the development of skills in accessing and applying available knowledge to promoting creativity and leadership with relevant and applied agricultural education programs.

The overall objective of universities in revising and reorienting their agricultural undergraduate curricula should be to produce graduates (scientists) who are able to conceptualize, implement and direct projects with producers; analyze ecological and conventional food production systems; integrate biology humanities, economics and ecology in food systems; use systems approach for complex problems; analyze policies on agriculture and food as they relate to sustainability; and process the right values toward people and the environment. However, such a holistic, interdisciplinary focus must rest on strong disciplinary pillars. Agricultural science will still require disciplinary specialists for the more basic and strategic research aimed at lifting productivity potentials in future. Postgraduate programs will be especially important in this.



Many university students enrolling in agricultural science courses do not have a vocational interest in the profession but are admitted on account of inflexible student selection criteria and admission policies and ability to pay. Significant investments are needed to excite students earlier in their careers about agricultural science and to support older scientists into becoming role models who engage in profitable professional businesses and constructive policy debates/formulation and mentor young scientists and investors. The existence of vibrant professional associations of agricultural scientists is crucial in providing the checks and balances in the profession and at individual level and also in reducing barriers among disciplines and between research and extension.

Balancing domestic investment and foreign assistance

Today, the lack of political commitment in the State House is the biggest single missing ingredient in building a strong and productive agricultural science base in Africa. China showed the way when its State Council recently issued a decree to pursue a new round of radical reforms to create a modern, responsive, internationally competitive and fiscally sustainable research system (Huang et al., 2003). Foreign aid can certainly assist the national agricultural research systems of Africa, but aid and foreign experts are no substitute for political leadership, time, learning by doing and learning from others. In short, building a science-based agriculture is an indigenously led, accretionary process.

Many national agricultural research systems in Africa are highly reliant on foreign aid, with most salaries supported from national budget allocations but nearly all operating costs and most capital purchases covered by donor grants or loans. Foreign assistance can be viewed in positive and negative terms. In positive terms, foreign aid has trained thousands of agricultural scientists. But erratic and large flows of aid to national agricultural research systems have created aid dependency in many countries in Africa. A recent study of Swedish foreign aid has found that, although Tanzania received about us\$2 billion of aid from Sweden over the 1970-96 period, it remains one of the poorest countries in the world (Catterson and Lindahl, 2003). In short, Swedish aid has contributed to aid dependency in Tanzania.

What is urgently needed is a radical rethinking of how Africa can best organize itself to take advantage of the world's rapid scientific progress. Clearly, Africa's scientific community cannot flourish if it continues to be heavily dependent on erratic foreign aid for 40 percent or more of the budget of its national agricultural research systems.



Some hard analytical work is needed on the tough questions of how to determine the long-term scientific and financial sustainability of a national agricultural research system. At present, economists do not have a practical appraisal tool to determine what size national agricultural research system a borrower should aim for and to define the indicators of success for achieving long-term scientific and financial sustainability. There is a dearth of information on how to analyze the borrower's long-term capacity to sustain its national agricultural research system without donor support. Since the issue of sustainability is masked in the early years of donor projects, when the donor pays a large share of the project, many national agricultural research systems have added hundreds of scientists without realizing that once the infrastructure is built, the main cost of research is salaries.

Funding higher education

It is the conviction of this Study Panel that much of what would be necessary to improve agricultural productivity and food security in Africa hinges on strengthening agricultural educational systems, more specifically the coverage and quality of higher education. The national resources of African countries will not be adequate for the huge task of strengthening higher education to a level that will produce the human capital with relevant training to face the challenges that food security poses for many regions of the African continent. The Study Panel calls on international financial institutions, such as the World Bank and the International Monetary Fund, to adopt policies that encourage public investment to strengthen higher education in developing countries and stimulate public expenditures in the highest-quality higher education possible.

Developing an agricultural research lobby

A final comment should be made on one of the principal underlying causes of inadequate funding to African universities, in particular from government budgets. Many observers argue that poor funding for agricultural education is directly linked to a lack of political savvy in most universities and faculties of agriculture. The faculties of agriculture remain on the fringe of the subregional research organizations – Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), Le Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles (CORAF) and Southern African Centre for Cooperation in Agricultural Research (SACCAR). Also, most faculties of agriculture do not hold annual



meetings to display their research findings to the Ministries of Agriculture, Higher Education and Finance, and the donor community. By contrast, the agricultural research lobby is skilled at courting and generating donor support. Without question, the CGIAR members, along with International Service for National Agricultural Research (ISNAR), Special Program for African Agricultural Research (SPAAR), FARA and subregional organizations are far better advocates than national agricultural research system for investment in research (Eicher and Rukuni, 2003).

What can universities do to emulate the agricultural research lobby? The World Bank's preparation of Multi-Country Agricultural Productivity Program (MAPP) for Africa presents a window of opportunity (World Bank, 2003). The Bank has developed MAPP and plans to mobilize US\$1.7 billion for agricultural research and extension in Africa over the coming five years. But the MAPP concept paper does not at present include funds to strengthen agricultural higher education in Africa. NEPAD should encourage the World Bank to get higher agricultural education included in the MAPP initiative.

Conclusions

The next generation of African scientists must have a strong and holistic science-based training within a socio-economic background that is relevant to the needs of society. The curriculum has to be flexible and market driven, incorporating aspects of sensitivity to the environment and sustainability, natural and social science, information technology and entrepreneurship; and it has to be able to produce scientists with commitment to life-long learning. They must be equipped with both problem-solving and critical thinking skills, and possess good communication and interpersonal skills.

African governments, with support from development partners, must pursue strategies that create incentives and opportunities for scientists to stay and work in their countries and to invest more in science and technology at all levels of education so as to create an attractive environment and demand for further s&t education. Incentive and reward systems should encourage innovation and entrepreneurships in the agricultural sector. Networking and partnerships may provide a viable and cost-effective mechanism for scientific capacity building.

The private sector has to contribute to agricultural research and support for higher education. Agricultural scientists need to be in harmony with political and policy initiatives at the highest levels so that they can effec-



tively articulate and prioritize their relevance and contribution, while ensuring ethical standards through professional associations and mentoring.

It has proven difficult for African governments and donors to design prepare and implement integrated programs of higher education in Africa because of bureaucratic problems between agriculturalists and educators in the various donor headquarters, and because of competition among universities, research and extension departments, and ministries in Africa. Indeed, both donors and national governments often actively oppose real coordination. Each has idiosyncratic priorities. As a result, a comprehensive approach to building agricultural knowledge systems will not be forthcoming until African scientists, educators, farmers and extension specialists stand up and say 'Enough!' One way forward is for African agriculturalists to seize the initiative and provide leadership in crafting country-specific agricultural knowledge systems (Rukuni et al., 1998). The next step is to sell this integrated institution-building approach to their political leaders and then to donors. Finally, deans of agriculture need to become more entrepreneurial and build political support among farmers, key government ministers and donors.

Recommendations

- ▶ Focus on current and future generations of scientists in Africa
- ▶ Broaden and deepen political support for agricultural science
- ▶ Reform university curricula
- ▶ Mobilize increased and sustainable funding for higher education in science and technology, minimizing dependence on external donor support
- ▶ Strengthen science education at primary and secondary school levels



References

- Anandajayasekaram, P., J.J. Woodend, M. Rukuni, R. Rose, and A. K. Kashuliza. 1996. Report on the impact assessment, costing, and tracer study of the SADC/GTZ project on strengthening postgraduate training in agriculture. Gaborone: Southern African Centre for Cooperation in Agricultural Research (SACCAR).
- Beintema, N.M., P.G. Pardey, and J. Roseboom. 1998. Educating agricultural researchers: A review of the role of African universities. EPTD discussion paper no. 36. International Food Policy Research Institute and International Service for National Agricultural Research. Washington, DC
- BIFAD (Board of International Food & Agricultural Development). 2003. Renewing USAID investment in global long-term training & capacity building in agriculture and rural development. Washington, DC
- Birdsall, N. 1996. Public spending on higher education in developing countries: too much or too little? *Economics of Education Review*, 15:4, 407-419.
- Castillo, G. T. 1997. Research Partnerships: Issues, Lessons, Results and Dreams for Sustainable Development. ODI Agricultural Research and Extension Network Paper no. 71. Overseas Development Institute. London.
- Catterson, J., and C. Lindahl 2003. What causes aid dependency? Evaluating thirty years of Swedish bilateral aid to Tanzania. Paper presented at the Fifth Biennial World Bank Conference on Evaluation and Development, Washington, DC 15-16 July 2003. World Bank Operations Evaluation Department. Washington, DC
- Court, D. 1999. Financing higher education at Makerere: the quiet revolution. *Human Development*, September 1999, 143-156.
- Echeverria, R. G., and H. Elliott. 2002. Financing agricultural research by competitive funds. In: Byerlee, D. and R. G. Echeverria. (Eds.) *Agricultural research policy in an era of privatization*. New York: CAB International.
- Eicher, C. K. 2003. Personal communications.
- Eicher, C. K., and M. Rukuni. 2003. The CGIAR in Africa: Past, present and future. OED working paper. World Bank Operations Evaluation Department. Washington, DC
- Fine, J. 1997. An African-based doctoral programme in economics: Summary report. Nairobi: African Economic Research Consortium.
- GNEST (Global Network of Ethiopian Science & Technology). 2003. Resurrection of Ethiopia through knowledge. GNEST. Addis Ababa.
- Huang, J., R. Hu, and S. Rozelle. 2003. *Agricultural research investment in China: Challenges and prospects*. Beijing: Financial and Economic Press.
- IAC (InterAcademy Council). 2004. *Inventing a better future: A strategy for building worldwide capacities in science and technology*. Amsterdam: InterAcademy Council. Accessible at <www.interacademycouncil.net>
- Lynam, J. K., and M.J. Blackie. 1994. Building effective agricultural research capacity: The African challenge. In: Anderson, J. R. (Ed.) *Agricultural technology: Policy issues for the international community*. Wallingford, U.K.: CAB International.
- Michelsen, H., L. Zuidema, C. Hoste, D. Shapiro. 2003. *Improving agricultural research at universities in Sub-Saharan Africa: A study guide*. The Hague: International Service for National Agricultural Research.
- Mrema, G. C. 1997. Agricultural research systems in the ECA sub-region. In: Mrema, G.C. (Ed.) *Development of a long-term strategic plan for agricultural research in the eastern and central African region*. Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA). Kampala, Uganda.



- Oniangio, R., and C. K. Eicher. 1998. Universities and agricultural development in Kenya: An agenda for renewal. Paper presented at the conference Transforming the Agricultural Research System in Kenya: Lessons for Africa. Bellagio Study and Conference Centre, Bellagio, Italy, October 1998.
- Psacharopoulos, G. 1994. Returns to investment in education: A global update. *World Development*, 22(9): 1325-1343.
- Rukuni, M., M. J. Blackie, and C. K. Eicher. 1998. Crafting smallholder-driven agricultural research systems in southern Africa. *World Development*, 26 (6): 1073-1087.
- Saint, W. 1992. Universities in Africa: Strategies for stabilization and revitalization. World Bank technical paper no.194. World Bank. Washington, DC
- Thimm, H. U. 1992. Professional manpower for agricultural development in SADC countries. *Agricultural Economics and Rural Development*, 2(1): 37-44.
- Till, G. 2003. Harnessing distance learning and ICT for higher education in Sub-Saharan Africa: An examination of experiences useful for the design of widespread and effective tertiary education in Sub-Saharan Africa. Rockefeller Foundation. New York.
- World Bank. 2002. Constructing knowledge societies: New challenges for tertiary education. World Bank. Washington, DC
- World Bank. 2003. A multi-country agricultural productivity program (MAPP) for Africa. World Bank. Washington, DC



7. Markets and policies to make the poor income and food secure

Forces of change, such as globalization, market liberalization, privatization, urbanization, HIV/AIDS, population growth, climate change and the changing proprietary nature of agricultural research redefine many of the problems to be addressed and the kinds of solutions available. It is imperative to develop and adapt national agricultural science and technology (s&t) policies within this changing environment, and these policies must also be viewed in a broad social and economic context.

While the uptake of improved technology options constitutes an important pillar for national agricultural growth, poverty reduction, food security and environmental sustainability, there are other crucial pillars that demand attention. Trade and market policies, infrastructure, education and health, access issues by the poor and environmental policy must all be considered. And these pillars also condition the context in which agricultural technology options are introduced and determine which ones are attractive to farmers. Efficient, fair and competitive markets are crucial for technology options to be sustainably adopted.

The interaction among science, technology and policy is of critical importance. The New Partnership for Africa's Development (NEPAD) provides a comprehensive approach that takes these factors into account. Efforts to strengthen science, technology and policy linkages for African agriculture should be fully integrated with NEPAD. This chapter addresses these contextual issues and their implications for national policies.

The changing context for national S&T policies

The context in which agricultural science and technology is undertaken is changing rapidly, and s&t policies must adapt appropriately.

Change in agricultural science

The nature of agricultural science is changing in fundamental ways as genetic engineering developments and intellectual property rights (IPR) rede-



fine the proprietary nature of many new technology options. Private research and seed firms are competing with – and in some cases displacing – some lines of public research, and IPR threatens to constrain access to improved genetic materials and research techniques for public research and development (R&D) agencies working on crop improvement and other problems of poor farmers. As the private sector increases its role in the traditional lines of genetic improvement for mainstream crops for commercial farms (small and large), the public sector can focus more sharply on the R&D problems of poor farmers, poor regions and natural ecosystem conservation and management – all of which are less likely to attract the private sector. The public sector also has important roles to play in conservation of African genetic resources, both in farmers' fields and in gene banks (especially for orphan and lost crops critical to food security) and in provision of safety nets for the poor and food insecure.

There is also scope for more effective partnerships between public and private research organizations. Although some types of research are public goods that the private sector will not undertake, this does not always mean that the public sector is best placed to undertake that research. Even when the public sector must pay, it might still be better to contract out the research to private firms – or other specialized agencies – that have a stronger capacity for the particular kind of work.

The IPR regimes (including patents, licenses, and breeders' rights) can encourage useful private sector investment in agricultural research and extension. But unless designed with care they can also lead to high social costs by restricting public access to new technology options and knowledge and to concentration in national seed markets (sometimes by multinational firms). This may deny farmers compensation for indigenous genetic materials that they have nurtured and husbanded over generations. Intellectual property rights not only benefit the private sector, but if managed properly, can be of benefit to the public sector. Unfortunately, most public sector institutions in Africa are ill equipped to effectively manage intellectual property and there is a need to strengthen their abilities in this respect.

Although the World Trade Organization (WTO) Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) provides broad guidelines for WTO member countries in writing IPR legislation, there is still much flexibility. The provisions of the World Intellectual Property Organization (WIPO) and the International Union for the Protection of New Varieties of Plants (UPOV) also require increased attention by African govern-



ments. Countries need to find the balance between private and public interests as well as national vs. regional research that is most appropriate for their needs. They also need to pursue access to technology through such institutions as the new African Agricultural Technology Foundation (AATF), which aims to provide private processes and materials protected by intellectual property rights, free of charge to public agricultural R&D institutions in Africa. The AATF is a good example of effective private-public partnerships.

New technology in food and agriculture is increasingly politicized, fuelled by publicity of perceived risks and little confidence in its benefits. In many cases, especially those involving genetic engineering, consumer organizations and the media are playing an increasingly more important role than farmers, science, business and industry in public acceptance or rejection. In this changing environment, African public research institutions need to redefine their roles vis-à-vis private research firms, and governments must adopt national IPR regimes that comply with WTO/TRIPS, the Convention of Biological Diversity (CBD) and the International Treaty on Plant Genetic Resources for Food and Agriculture. They must also develop and implement acceptable biosafety regulation systems that ensure food and environmental safety and build public confidence. With the large number of small countries in Africa it would seem that a regional approach to biosafety regimes should be encouraged. In this way the costs of establishing regulatory regimes for genetically modified organisms (GMOs) may be substantially reduced, even though of necessity it will be largely a national and local responsibility to set up and implement monitoring and evaluation processes.

Persley (2003:5), in her synthesis of 50 science-based reviews of modern genetics and its applications in food and agriculture and the environment, indicates that 'The cost, complexity, and uncertainty of regulation in new genetics in food and agriculture make regulatory requirements a barrier to entry for public research institutes, poor countries, and small companies.' Public-good agricultural research in Africa will miss the opportunities of the new genetics without concerted regional efforts to economize on the requirements of establishing the regulatory regime.

There is usually a trade-off between the cost and feasibility of a regulatory system and the level of biosafety achieved. Also, the lower the level of risk that is tolerated, the more likely there will be lengthy delays before release of new technology that could make important contributions to national economic growth, food security, poverty reduction and environmen-



tal sustainability. These trade-offs will vary with the capacity of a country to undertake effective biosafety regulation and with the type of technology to be evaluated.

Countries will also place different social values on the trade-offs depending on their levels of wealth, the importance of the agricultural sector, and the degree of urgency in solving food and nutrition problems. Large countries like South Africa or Nigeria can afford more costly systems, and they have the capacity and trained people needed for implementation. But many smaller countries in Africa cannot afford the same degree of investment, nor do they have enough capacity and trained people to implement ambitious biosafety regulatory systems. Regional biosafety systems offer the best solution to this problem. These should be based on agreed objective risk assessment founded on sound scientific bases. Harmonization of biosafety standards and cooperation among countries can facilitate such regional approaches, with economic benefits to all. Risk assessment could be conducted in a few countries that typify the major agro-ecologies and farming systems and the results accepted by cooperating countries. This would obviate the necessity to duplicate risk assessments in every country with similar ecologies or systems. Of course the decision to release GMOS would remain the sovereign right of each country. Current efforts by the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) show a possible way to proceed in this respect.

Globalization

Globalization is increasing the competition that Africa's farmers face from cheap, often subsidized food imports. Trade-distorting policies by the Organization for Economic Co-operation and Development (OECD) countries are particularly harmful to African agriculture because of agricultural subsidies (mostly the European Union and the United States), limited market access (European Union, Japan and the United States) and export subsidies (mostly the European Union). Countervailing responses by African governments will not be in the best interests of the poor and food insecure. National, regional, continental and international markets should be competitive, free and fair for African farmers and consumers. Export markets for Africa's traditional export crops are also being challenged by new suppliers from Asia and Latin America, and rich importing countries are becoming choosier about product quality and standards. New export opportunities are emerging for nontraditional export crops, livestock production and processed foods, but mostly for producers who are well connected to



markets and who can meet quality standards. However there is potential for Africa to benefit from globalization and trade liberalization; this is outlined in Box 7.1. To capitalize on this potential requires regional, national and local markets to be linked more explicitly than they are currently.

In order to enhance competitiveness, new technology options are needed that reduce unit costs of production, improve product quality and add

Box 7.1 The benefits of globalization and trade liberalization to Africa

In the past two decades, Africa has lost ground in the global market place for its traditional export crops (coffee, tea, cocoa, tobacco, sugar and cotton). Its share of world exports fell from about 4 percent in the early 1980s to 2 percent in the late 1990s (IFPRI, undated). This illustrates that Africa's productivity growth and quality improvements have fallen behind those of its competitors.

The good news is, using economic simulation models, Runge and colleagues (2003) have estimated that Sub-Saharan Africa stands to benefit most from trade liberalization, in terms of the share that such economic benefits would represent of the value of agricultural production and of gross domestic product (GDP) (Table 7.1). West Asia and North Africa also stand to benefit, though not to the same extent as Sub-Saharan Africa. Together they would represent 21 percent of the total world gains, a disproportionately large share. These benefits arise from improvements in economic effi-

ciency from reduced producer and consumer subsidies, with attendant tax savings and trade liberalization through reducing tariff and other barriers. They illustrate the importance of competitive, free and fair markets at all levels to Africa. The Study Panel heard this plea consistently during its consultative processes around Africa.

Globalization could also lead to significant improvement in food security, especially for net exporters, due to higher prices that they would receive. African farmers would also face less competition after removal of subsidies on exports from European and other developed countries. Also the removal of taxes that most African governments impose on food production and consumption would stimulate farm investment and lower food prices. Sub-Saharan agricultural exports would increase by US\$10.7 billion, a 45 percent increase.

Table 7.1 Net gains in economic welfare from global trade liberalization towards 2025

Region/Country	US\$ billion	As % of value of agricultural production	As % of GDP
Developed countries	13.2	2.9	0.03
Developing countries	19.3	2.6	0.10
Sub-Saharan Africa	4.6	10.5	0.91
West Asia/North Africa	2.1	5.5	0.10

Source: Runge et al. (2003: 64). The analysis uses the IFPRI IMPACT- WATER model, which includes 16 agricultural commodities.



value. This would be essential to market-led productivity change as described in Chapters 4 and 5, and holds true for on-farm production, post-harvest storage and treatment, agro-processing, marketing and transport. Post-harvest losses in Africa are high, and there is good scope to reduce these through improved roads and markets, together with active encouragement of private sector investment in research and development at the lower end of the production-to-market chain. Creative partnerships between the public and private sectors, such as the African Agricultural Technology Foundation, can also open up new and innovative institutional and technological opportunities.

Enhancing the benefits from research and development

The impact of agricultural research and technology on national economic growth, poverty reduction, food security and environmental sustainability will depend on complementary interventions such as trade and market reforms, infrastructure investments, education and health policies, access issues by the poor, and environmental policy. In this milieu, African governments will need to strengthen the scientific basis of their policymaking.

Urbanization, expanding markets and trade opportunities

Africa is rapidly urbanizing, and by 2020 almost half the African population will live in urban areas (Rosegrant et al., 2001). This will be an engine for most national market developments. Although peri-urban agriculture can be an important source of food, urban people depend primarily on purchased rather than homegrown foods. They also usually consume less coarse grains, roots and tubers, and more livestock products, fats, fresh horticultural products, and processed and pre-cooked foods. This offers important new opportunities for agricultural diversification into higher value products for African farmers, agro-industry, and food wholesaling and retailing. Marketing chains are also becoming more integrated in urban areas with the rise of supermarkets and convenience shops. Agricultural research will need to address the problems of an increasingly diverse array of crop, tree and livestock activities, and give more attention to post-harvest storage and processing properties, as well as rural to urban markets. The private sector should have an important role to play in these kinds of research.

Modern technologies requiring external inputs only have a chance of adoption when smallholders produce for the market. However, with poorly



developed markets and infrastructure, trying to produce for them can be highly risky and economically unattractive. Stifel and colleagues (2003), for instance, found that the incidence of poverty in rural Madagascar increases with remoteness, the yields of major staple crops fall considerably and the use of agricultural inputs declines as one moves farther from markets.

Nevertheless, when markets eventually develop, transport and transaction costs usually decline substantially, which make production for the market more attractive. The difficult and risky start-up phase of market development impedes the transition from subsistence- to market-oriented agriculture. Along similar lines, Omamo and Lynam (2002) argue that subsistence farmers are further constrained by their own learning and production routines.

Market reforms in Africa are seen to have been necessary, but they have not gone far enough to generate greater supply response and competitiveness in export markets (Kherallah et al., 2002). Market liberalization may have removed price distortions, but it did little to benefit most small-scale farmers, especially those living away from roads and markets. Indeed, high transaction costs and the limited development of private trade are forcing many small-scale producers back towards subsistence modes of farming. Without opportunities for export, successes in expanding production frequently result in large price drops because of inelastic domestic demand.

Africa currently imports 25 percent of its food grains. This offers scope for better integration of domestic and intraregional food-grain markets within Africa and expanded intra-African trade, which can place a floor on grain prices. However, such integration is currently constrained by poor regional infrastructure, institutions, market coordination and competition from low-cost and often subsidized imports from OECD countries. Recent research suggests that reducing marketing margins and increasing the productivity of the grains and livestock sectors, in tandem, would have a greater impact on income and food consumption growth in Africa than increased export growth in the traditional and nontraditional export sectors alone (Diao et al., 2003).

Growing competition in export and domestic markets also makes it imperative that African farmers meet more stringent demands for grading and food quality/safety standards and strive to differentiate their products from competitors. Several things are needed: (a) increasing attention to market development (e.g., strengthening institutions responsible for standards and quality control, enforcement of contracts, market information and product promotion); (b) strengthening market-support services (e.g., credit and oth-



er financial services, transport, refrigeration and storage); (c) improving rural infrastructure (especially roads, information and communications technology and telecommunications) and (d) reinforcing policymaker commitment to market reforms. Nongovernment organizations (NGOs), producer organizations and the private sector could play a greater role in facilitating the development of effective marketing institutions, particularly in remote areas. Price information systems developed using the Kenya Agricultural Commodity Exchange are innovative examples of best practice in this regard.

With more liberalized markets, farmers and consumers are now exposed to more volatile prices than before, and this is impacting on the vulnerability of the poor and on farmers' willingness to invest in new technology options. Some forms of market mediation – such as efficient and targeted input subsidies, safety net programs, subsidies for provision of environmental services provided by farmers where market failure leads to inferior societal outcomes and market-based risk management interventions (e.g., weather insurance and futures price contracts) – may still be needed. There are new institutional possibilities for these kinds of instruments today.

Investing in rural infrastructure

Inadequate investments in rural development have taken a severe toll on the provision of infrastructure and services. The road system in Africa today is only a fraction of what India had decades ago (Spencer, 1994) and leaves about 70 percent of its farmers poorly connected to markets. Many farmers can neither procure fertilizers and other inputs at affordable prices nor market their own products effectively. Poor telecommunications infrastructure also keeps farmers in isolation. Similarly, poor access to health and education services diminishes agricultural productivity, contributes to the spread of infectious diseases and locks rural people into a poverty trap. Box 7.2 outlines the benefits of increased infrastructure investment.

Africa's low population densities make per capita infrastructure investment and maintenance costs high and difficult to finance. Capacity building in Africa should not be limited to science and technology but also involve technical and vocational training for staff of agro-service centres, engineers to maintain infrastructure and machines. New technologies present alternatives to expensive conventional large-scale infrastructure development, often difficult to maintain. The use of wireless communication technologies and the convergence of technologies give new affordable possibilities for telephony and Internet access. Wind and solar power can be viable alternatives to



conventional sources of energy. Encouraging greater use of locally available labour could contain the costs of feeder roads. Encouraging greater local ownership of investments through co-financing arrangements and by devolving responsibility for maintenance to local governments and communities addresses many previous problems associated with upkeep.

Achieving realistic levels of infrastructure and rural services will require substantial increase in public investment. Public investment in rural areas has fallen in many African countries in the past decade or so due to the fiscal pressures imposed on governments through structural adjustment programs and a precipitous decline in donor support for such fundamentals

Box 7.2 Increased investment in infrastructure lifts productivity and benefits the poor

A recent International Food Policy Research Institute (IFPRI) study evaluated the returns to public investments in rural Uganda. The results show that government investments in agricultural research have had the most favourable benefit-cost ratio for growth of all public investments and they raised more people above the poverty line for each 1 million Ugandan shillings (Ush) spent (Table 7.2).

Roads

Investments in roads also have a very attractive benefit-cost ratio and the second largest impact on poverty reduction. The impact of low-grade feeder roads on poverty is much larger than of

high-grade roads, such as murrum and tarmac roads, mainly because feeder roads impact significantly on poverty reduction and agricultural productivity improvement, while murrum and tarmac roads had no significant impact on agricultural productivity. The impacts of the murrum and tarmac roads on poverty reduction are mainly through improved non-farm employment opportunities.

Education

Education investments, which rank third in terms of growth and poverty reduction, benefit the poor by lifting agricultural productivity and non-farm employment and increasing rural wages.

Health

Government spending on health did not show a large impact on growth in agricultural productivity or on rural poverty. This is probably because much of the current expenditure is on prevention and treatment of HIV/AIDS-related diseases, for which the benefits are not captured in the relatively short data series available for this study.

Win-win investment

The implications for Uganda are that increasing current research intensity from the low level of about 0.5 percent of agricultural GDP would be a win-win investment. Increased investment priority should also be accorded to feeder roads and education.

Table 7.2 Returns to government investments in rural Uganda

Investment	Benefit/cost ratio	Reduction in numbers of poor per million Ush
Agricultural research and extension	22.7	107.2
Education	2.7	12.8
Feeder roads	20.9	83.9
Murrum roads	n.s.	40.0
Tarmac roads	n.s.	41.4
Health	0.6	2.6

Source: Fan et al. (2003).

Note: n.s. denotes effects were not statistically significant.



(Fan and Rao, 2003). The over-zealous downsizing of the public institutions that provide essential public goods and services like research and development, infrastructure, education and health will also need to be reversed. These institutions have key roles to play and need to be revamped and strengthened to fulfill their functions in cost-effective and demand-responsive ways.

Strengthening producer organizations

Structural adjustment and market liberalization that removed African governments from many market and service functions have created both a vacuum and an opportunity. The hasty retreat of government from service delivery to rural communities without a credible back-up plan or set of alternatives in place has left many communities and farmers fending for themselves. In many cases these shocks have worsened the conditions of the rural communities and created political backlashes, causing backsliding on market reforms. Amidst the acrimony, there is growing understanding that the future belongs to the organized.

While the private sector is emerging as a key player in linking larger-scale commercial farmers with markets, voluntary producer organizations of various types, such as co-operatives, will have important roles to play in providing the basic linkages between small-scale farmers and businesses (agro-service centres, food processors, manufacturers, traders, supermarkets and other food outlets) that do not have the ability or will to deal with small-scale farmers on an individual basis. Simply because farms are small in size does not imply they are not commercially viable per se or that they can become so. Indeed many large-scale commercial farms, especially state-owned ones, are not economically viable. A distinction must be made between small farms and resource-poor farmers. Small farms in Africa have scope for sustainable intensification that is productive, profitable and environmentally sound, provided they have equitable access to input and output markets, credit, innovations, knowledge and information.

Linking farmers and businesses creates opportunities, adds value to producer efforts and helps serve businesses by providing an efficient conduit to reach the mass of small-scale producers. Such producer organizations will play a central role in gaining value from market and trade systems development, investing in technology systems and improving access to micro-finance. Effective producer organizations can also add to the social capital of a community, enhancing the likelihood of effective cooperation in areas such as natural resource management. Farmer organizations in sev-



eral African countries have successfully strengthened farmers' market participation.

Investments in strengthening producer organizations should have the following benefits: lower marketing margins and higher prices for producers; improved product quality; increased access to extension, input and financial services; and greater participation by the rural majority in decision-making processes.

Unlike former state co-operatives that are widely discredited because of their poor performance and high cost, key design principles for future organizations will ensure they are voluntarily organized, economically viable, self-sustaining, self-governed, transparent, and responsive to community and producer-based groups. Supporting these kinds of organizations will require government and donor involvement, engaging with businesses, NGOs, and other civil society groups.

Investing in people and institutions

Development of human capital and institutions is critical for achieving agricultural growth. Over the past decade there has been significant policy reform, and limited institutional reform. Many of the institutions that were created during central government control of markets and services were ill equipped to work in a liberalized market environment. Good policies and investments can go sour, not because they are poorly conceived but because the institutions that implement them do not work well.

Reform of public institutions must overcome vested interests; otherwise new forms of rent-seeking and corruption simply replace the old. New actions may be needed; increased donor support of key public sector investments could come from new financing arrangements that empower the users of public services (e.g., vouchers, user fees, and other co-financing mechanisms) with appropriate institutional reforms to improve mandates and performance.

It is critical to form new partnerships between the public, private, and NGO sectors for the provision of public services such as credit, extension and research. Even where governments must pay all or most of a service, this does not mean they necessarily have to supply it themselves. Contracting out arrangements with other parties can be much more cost-effective, and may offer better possibilities for involving local people and communities. The types of partnerships desired will vary by sector and function. It may be more opportune to diversify supply arrangements for education and health services, for example, than to provide rural roads and market regulation.



Targeting vulnerable groups

Broad-based agricultural growth centred on small farms would make deep inroads into poverty and hunger in Africa. Each 10 percent growth in agricultural productivity in Africa has been shown to reduce poverty by 6 percent. Stated differently, with more than 110 million poor in Africa, a 10 percent increase in crop yields can help almost 7 million more people raise their incomes above the poverty line of us\$1 per day (Thirtle et al., 2001). At this rate, a smallholder-led growth strategy could lead to huge cuts in Africa's rural poverty and enhanced food security within a couple of decades. But even this will not be enough to alleviate poverty or to reach the poorest of the poor. There is also need for targeted investments in the poor and food insecure and the establishment of effective safety nets.

There have been real advances in recent years in targeting and delivering assistance more effectively, often by involving local communities in the design and implementation of targeted programs. But safety net programs are still costly, and there is need for better integration of relief with development efforts. The objectives of these efforts should include (a) helping the chronically poor and hungry in rural Africa find viable pathways out of poverty by helping them to accumulate assets such as land and credit; (b) reducing the vulnerability of poor and near-poor people to weather, markets and conflict-induced shocks; and (c) enhancing the capacity of countries to manage shocks that have regional and national impacts.

It is important to develop national capacities for food insecurity information systems to identify the chronically food insecure, their location, their livelihood systems and the nature and causes of their food insecurity and vulnerability. Such information is critical to efficiently design and target appropriate policies and interventions. Such information is also necessary to target food aid during crises.

Africa, unlike South Asia or Latin America, is fortunate that most countries have relatively equitable land distribution. East Asia also had relatively equal land distribution, which makes increasing crop yields a powerful anti-poverty instrument. What is unequal in Africa is farmers' access to new technology and access to both input and output markets. Although only a few countries in Africa (such as Zimbabwe and South Africa) have a land reform program, satisfactory resolution of this issue is crucial to future stability and food security. Land redistribution is a challenging political process. Market-mediated reforms have been tried, but the results are ambiguous at best.

There is a need for more secure tenure for smallholders to facilitate access to credit, so vital to technology adoption and productivity growth.



Customary or usufruct tenure, while effective in traditional agriculture, does not confer the necessary ‘ownership’ to establish the required collateral with institutional credit institutions in the event of loan defaults. There are examples in Uganda where introduction of land titling has succeeded in this way while also protecting women’s land rights. Hence land titling should be explored by countries to examine whether it could improve access of smallholders to credit. Land titling is distinct from land reform. With the increasing availability of information and communications technology such as satellite imagery, remote sensing, geographical information systems, and the global positioning system, there is now good scope to apply these to codify African land tenure.

Microfinance institutions have proved effective in providing services and increasing assets of the poor. They are valuable mainly for non-farm investment, however. Improving smallholders’ ability to save and invest requires the development of an entire rural financial infrastructure that enables farmers to deposit and withdraw cash, receiving a competitive interest rate on their deposits and paying a competitive rate on their withdrawals.

The central goal is to assist the chronically poor through broad-based agricultural growth. Many small-scale farmers will need to diversify into high-value products to exploit their comparative advantage and to increase value added per person and per hectare. They will need to organize to obtain better access to markets and better terms in the market. Small-scale farmers, both male and female, should receive greater priority in agricultural research and extension and in credit programs.

Poor people have complex livelihood strategies, and agricultural development is rarely sufficient on its own to eliminate poverty. Increased investments in rural health, education and training, in conjunction with agricultural programs, combine to form a key tool to reduce vulnerability, because healthier and more educated people are usually able to adjust more quickly to changing circumstances. Multi-sectoral approaches to reduction of poverty and malnutrition are essential, involving the promotion of health, education and clean water, as well as increases in food supplies and non-farm sources of income.

Investing in environmentally sound development pathways

Land degradation and the unsustainable use of natural resources are limiting the potential for agricultural development in Sub-Saharan Africa. Encroachment into fragile areas, reduced duration of fallows, continued low levels of input use and limited adoption of available resource-conserving



practices underlie the problem. Improvements in marketing and access to input services and credit will be important for promoting more widespread adoption of these technology options. In some cases, farmers also need more secure property rights or more effective local institutions for managing common property resources and encouraging investments in longer-run land-conserving technology options.

Governments need to develop more effective land-use planning strategies and the means to implement them within the framework of customary land tenure arrangements, which mostly work well in Africa. Growing population pressure can sometimes help induce the adoption of labour-intensive technology options to improve land and other resources and reduce degradation (Boserup, 1965; Tiffen et al., 1994), but in practice sustainable pathways to intensification typically require other key interventions such as improved access to roads and markets, non-farm income-earning opportunities and improved technology options (Pender et al., 2001).

A case can be made for selective subsidies on strategic inputs, such as fertilizers, until infrastructure can be improved to the extent that prices paid and received by African farmers are more in line with international competitors. During the 1990s inorganic fertilizer use in Sub-Saharan Africa decreased from 10 to 8 kilograms per hectare. Most of this was applied to commercial non-food crops and some to food crops such as maize that are widely traded. The current annual rates of nutrient depletion of nitrogen, phosphorus and potassium between 50 and 100 kilograms per hectare in Africa means overexploitation of already depleted natural resources is rapidly leading to a downward spiral of productivity. Intergenerational equity hence provides an additional rationale for fertilizer subsidies; Breman and Debrah (2003: 157) point out that 'The paradox of African agriculture is that agricultural development is inhibited at once by overexploitation of the land because of overpopulation, and by poor market development because of underpopulation.' They refer to an additional paradox whereby those African countries that subsidized fertilizer prices or had government price control had growth rates of fertilizer consumption in the 1990s of 1 percent per year, whereas those without controls or subsidies experienced a 6 percent annual growth rate. Clearly soil fertility conservation and management policy remains a complex issue in Africa.

Government, NGOs, community-based organizations, the private sector and individuals all have a potential role in the dissemination of inputs and information on technology options that will lead to improved land man-



agement. Here information and communications technology can be a catalyst, as described in Chapter 4. In general, strong community-based institutions offer the greatest potential for the exchange of information on new technology options. Strengthening farmer organizations and other community-based organizations will facilitate innovation and adoption of natural resource conservation technology options. NGOs also have significant potential to have a lasting impact on land management through the development and dissemination of land management technology options and by organizing communities for successful collective action. Despite the potential for increased involvement of NGOs, community-based organizations and the private sector, governments still have critical roles to play in providing adequate finance for technology development and dissemination efforts, ensuring that environmental and other externalities are taken into consideration and pursuing strategies suited to marginal areas and the poorest rural people.

Although many of the interventions already mentioned will improve incentives and local capacities for rural people to manage natural resources in more sustainable ways, this will typically not be sufficient to achieve the levels of environmental stewardship demanded today by national and international interests. There remains a fundamental problem – markets do not reward rural people for the environmental services they provide when they grow trees, protect watersheds, or conserve biodiversity. Without such compensation, rural people will provide less of these services than desired by society at large. This will result in further environmental degradation, with consequent adverse impacts on agricultural productivity growth and food security.

A common solution to this problem is for government to regulate some resource management practices. For example, tree cutting is often banned or regulated in hillside areas, and certain land uses may be prohibited at sites where they are particularly degrading. At the extreme, sites of especially high environmental value are often converted to parks or conservation areas. Such approaches tend to work against the interests of local people, worsen the plight of the poor, and create incentives to cheat, all of which adds to the difficulty and cost of a regulatory approach.

More promising approaches are based on emerging markets for environmental services. Such markets can change incentives and benefit the poor. For example, as a result of global agreements to cut greenhouse gas emissions, markets already exist that require large users of energy (e.g., oil and electricity companies) to pay for each tonne of carbon sequestered in



forest or farmland. High transaction costs and difficulties in monitoring and enforcing contracts limit the prospects for most African farmers to benefit from such markets unless they can be effectively organized for this purpose.

Fair trade arrangements are another way of trying to capture higher prices to pay poor indigenous producers for some of environmental benefits that they generate. There are several successful examples involving non-timber tree products, such as nuts, honey and medicines. As more countries formalize property rights over genetic resources, there may be new opportunities for communities to use farmers' rights to collect royalties on some of the indigenous biodiversity that they conserve.

Innovations along these lines are constrained by the lack of an expressed market demand for most environmental services. Although environmental services are increasingly appreciated by society, there is little tradition or expectation of having to pay for them. International environmental agreements (e.g., the Kyoto Agreement to reduce carbon emissions) can be effective in bringing the needed pressure to bear, and perhaps similar agreements can be developed for some other environmental services.

New and emerging technology options such as genetic engineering, information and communications technology, and geographic information systems (GIS) also offer opportunities for better management of natural resources. Remote sensing and GIS tools allow for empirical analyses of land-use change over time and in a spatial context. Genetic engineering to raise productivity allows farmers to produce more output with less exploitation of natural resources. For many regions of Sub-Saharan Africa that depend upon one or two staple crops that are prone to pests and diseases, new crops that offer resistance have enormous implications for food security and rural livelihoods in general. As food security and incomes improve, farmers will be more likely to invest in natural resource management options offered by new technology.

Good governance

Success of the above-mentioned policies will require good governance, such as the democratic decentralization processes under way in Uganda. An effective public sector is essential for private-sector-based economic growth and eradication of poverty and food insecurity in Africa. Governments must develop a vision for agriculture that will be backed up with sound strategies and allocation of the necessary financial and technical resources. It is the Study Panel's view that the low priority given to agricul-



ture and rural areas by governments of most African countries is the main reason for the poor performance, not only of the agricultural sector, but also of African economies in general.

As NEPAD recognizes, good governance also implies the enforcement of law and order and the absence of corruption. Widespread conflict in many African countries, as well as failure on the part of the government to maintain law and order, are important reasons for the existing food insecurity and poverty. Where conflict has been replaced with law and order – such as in Mozambique and Uganda – transient and endemic hunger and poverty have been reduced significantly. However, the continual absence of conflict does not ensure that hunger and food insecurity will disappear. It remains a necessary but not a sufficient condition.

Investment requirements to improve food security in Sub-Saharan Africa

Improved agricultural productivity from greatly enhanced public investments in agricultural research and extension will play a key role in achieving and sustaining measurable improvements in African food security. The Study Panel recognizes that such improvements must be accompanied by ancillary public investments. These include investments in education, especially of women, access to clean water, rural roads and irrigation. These must be complemented by private investments in inputs such as fertilizers, farm and post-harvest machinery, and vehicles.

The Study Panel urges governments and international agencies to respond to the need for a renewed commitment to African agricultural research and development and help to make food insecurity a thing of the past. To illustrate the magnitude of the task, yet its feasibility, estimates have been made of the public investments required on the items above to reduce the number of malnourished children in Sub-Saharan Africa by 33 percent – from the 1997 level of 33 million to 22 million in 2020 (Rosegrant et al., 2001). Projected investments between 1997 and 2020 would need to increase by 71 percent, achieving an aggregate total investment of US\$183 billion compared to a baseline or most likely scenario level of US\$107 billion over the same period. This amounts to an increased investment of only US\$4.27 per person in Sub-Saharan Africa per year.

To achieve these reductions in child malnutrition would require realized crop yield annual growth rates of between 2.7 and 3.6 percent from 1997 to 2020. These rates are double those in the baseline scenarios examined, but achievable, as we have seen in Chapter 4. They may imply a 10 percent annual growth in fertilizer use, a level commensurate with the 9 percent



annual growth in Asia from 1960-95. Rates of female schooling are projected to rise by 20 percent in this scenario, with access to clean water and female life expectancy both increasing 10 percent.

Conclusions

If a market-driven agricultural productivity recovery is to be initiated, improved governance, market access, information, transport and communications are vital complements to science and technology. Increased domestic market opportunities for both food and non-food commodities depend crucially on improved access by Africa to international markets and seamless intra- and inter-regional trade within Africa. The former is constrained by OECD agricultural subsidies and increased use of non-tariff barriers as tariff rates are reduced under the WTO regimes. If trade is to become an instrument of hunger and poverty alleviation, it must be free, competitive and fair. Many otherwise viable technology options for Africa produced by past research remain under-exploited because of high input prices and low output prices that result from under-investments in markets and infrastructure, structural adjustment programs and distortions in international markets. The scale of the increased investments needed to make a real difference in agricultural productivity growth and improved food security are well within the reach of African governments and the international community.

Creating an effective policy environment, capable of exploiting the potential that science and technology offers, will require innovative ways to engage smallholders to become better informed and more active participants in markets, policy processes and priority setting in agricultural research and development. African countries need increased capacity to address product quality, comply with biosafety standards and phytosanitary requirements, and work with regulatory regimes related to GMOS. They also need the skills to negotiate effectively with OECD-importing countries. Only then will the private sector express its unrealized potential to contribute to the agricultural productivity recovery.



Recommendations

- ▶ Increase investments in rural infrastructure
- ▶ Strengthen capacity to expand market opportunities
- ▶ Institute effective intellectual property rights regimes to encourage the private sector and facilitate public-private partnerships
- ▶ Reduce barriers to increased African trade with OECD countries
- ▶ Improve data generation and analysis related to agriculture, food and nutrition security, and vulnerability



References

- Boserup, E. 1965. The conditions of agricultural growth: The economics of agrarian change under population pressure. New York: Aldine Publishing Company.
- Breman, H. and S. K. Debrah. 2003. Improving african food security. *SAIS Review* Vol. XXIII, No. 1 Winter-Spring 2003, 153-170.
- Diao, X., P. Dorosh, and S. M. Rahman. 2003. Market opportunities for African agricultural products: An examination of demand-side constraints on agricultural growth. Discussion paper no. 2. Development Strategy and Governance Division. International Food Policy Research Institute. Washington, DC
- Fan, S. and N. Rao. 2003. Public spending in developing countries: Trends, determinants and impact. EPTD discussion paper. International Food Policy Research Institute. Washington, DC
- Fan, S., X. Zhang, and N. Rao. 2003. Public expenditure, growth and poverty reduction in rural Uganda. Discussion paper. Development Strategy and Governance Division. International Food Policy Research Institute. Washington, DC
- IFPRI (International Food Policy Research Institute). Undated. Exploring market opportunities for African smallholders. Washington, DC
- Kherallah, M., C. Delgado, E. Gabre-Madhin, N. Minot, and M. Johnson. 2002. Reforming agricultural markets in Africa. Baltimore, Maryland: Johns Hopkins University Press.
- Omamo, S.W. and J. Lynam. 2003. Agricultural science and technology policy in Africa. *Research Policy*, 32: 1681-1694.
- Pender, J., P. Jagger, E. Nkonya, and D. Sserunkuuma. 2001. Development pathways and land management in Uganda: Causes and implications. EPTD discussion paper No. 85. International Food Policy Research Institute, Washington, DC
- Persley, G.J. 2003. New genetics, good and agriculture: Scientific discoveries – Societal dilemmas. Executive Summary of ICSU synthesis report.
- Rosegrant, M.W., M. S. Paisner, S. Meijer, and J. Witcover. 2001. Global food projections to 2020: Emerging trends and alternative futures. International Food Policy Research Institute. Washington, DC
- Runge, C. F., B. Senauer, P. G. Pardey, and M. W. Rosegrant. 2003. Ending hunger in our lifetime: Food security and globalization. International Food Policy Research Institute. Baltimore, Maryland, and London, U.K.: Johns Hopkins University Press.
- Spencer, D. 1994. Infrastructure and technology constraints to agricultural development in the humid and subhumid tropics of Africa. EPTD discussion paper no. 3. International Food Policy Research Institute. Washington, DC
- Stifel, D., B. Minten, and P. Dorosh. 2003. Transactions costs and agricultural productivity: Implications of isolation for rural poverty in Madagascar. Market and structural studies division discussion paper no. 56. International Food Policy Research Institute. Washington DC
- Thirtle, C., L. Lin, and J. Piesse. 2001. The impact of research-led agricultural productivity Growth on Poverty in Africa, Asia and Latin America. Working paper, Department of Environmental Science and Technology, Imperial College of Science, Technology and Medicine. London, U.K.
- Tiffen, M., M. Mortimore, and F. Gichuki. 1994. More people, less erosion: Environmental recovery in Kenya. Chichester, U.K.: Wiley.



8. Strategic recommendations

Africa has some unique features that differ from Asia, where the Green Revolution had such a pervasive impact. Recognizing these is an essential prerequisite to the formulation of strategies and priorities in science and technology (s&t). They became clear during the Study Panel's deliberations and shaped its recommendations.

The eleven distinct features of Africa are as follows:

- lack of a dominant farming system on which food security largely depends,
- predominance of rainfed agriculture,
- heterogeneity and diversity of farming systems and the importance of livestock,
- key roles of women in agriculture and in assuring household food security,
- lack of functioning competitive markets,
- dominance of weathered soils of poor inherent fertility,
- underinvestment in agricultural research and development (R&D) and infrastructure,
- lack of conducive economic and political enabling environments,
- large and growing impact of human health on agriculture,
- low and stagnant labour productivity and minimal mechanization,
- predominance of customary land tenure.

These delineate the options available to science and technology to influence productivity and imply that African agriculture is more likely to experience numerous 'rainbow evolutions' that differ in nature and extent among the many systems, rather than one Green Revolution as in Asia, where irrigated rice-wheat systems predominated. Hence more investment in agricultural research and development per unit of productivity gain will likely be required in Africa than was the case in Asia.

Improving agricultural productivity and food security in Africa will involve numerous challenges. The Study Panel has referred to them throughout the report. In this chapter the recommended responses to



these challenges are described under five strategic themes:

1. Science and technology options that can make a difference,
2. Building impact-oriented research, knowledge and development institutions,
3. Creating and retaining a new generation of agricultural scientists,
4. Markets and policies to make the poor income and food secure, and
5. Engaging science and technology for the benefit of African agriculture in the near term.

Following are the Study Panel's strategic recommendations with an elaboration of their background, rationale and implications. Table 8.1 at the end of the chapter provides a summary of the target audiences for the strategic recommendations and the time frame for initial impact. The relevant recommendations for each of the target audiences are also identified in Annex B.

The Study Panel purposely refrained from prioritizing the strategic recommendations. All the recommendations encompass the essential elements of an operational agricultural s&t strategy for Africa. And they represent the best prospects for meaningful impact on agricultural productivity and food security towards 2015. The precise priorities and action plans have to be developed by local consortia for the United Nations Millennium Development Goals and must be based on untapped production opportunities on the one hand, and unmet needs in overcoming chronic and hidden hunger on the other.

1. Science and technology options that can make a difference

Recommendation 1.1: Adopt a market-led productivity improvement strategy

A strategy of market-led productivity improvement should be embraced in order to achieve a balance between demand and supply, thereby providing incentives for farmers to close existing yield gaps and become more income secure in the process. Allowing farmers to respond effectively to price signals will result in more productive systems. This involves strengthening the competitive ability of farmers by using information and communications technology to provide speedy and timely market and price information, identifying new niche value-added marketing opportunities, quality literacy (including phytosanitary and safety standards), and encouraging and promoting farmer organizations, including co-opera-



tives. Such a market-led productivity strategy implies in the first place strengthened local and regional markets. The emphasis has to be on increasing local consumption particularly by those who are undernourished. Farmers need to organize themselves to strengthen their market orientation and in that process to encourage partnerships with the private agroservice sector, firstly for local and regional markets. African companies should be encouraged by appropriate incentives. Opportunities to improve post-harvest handling to minimize losses and to add value to primary products need to be grasped along with improved grading, packaging, cooling and storage in order to promote exports. These will help to create expanded opportunities for non-farm employment as agricultural productivity improves and frees up labour.

Farmer organizations also need to partner with research, education and extension organizations in a market-driven participatory knowledge quadrangle, which effectively links innovation, information, knowledge and education. Women farmers need particular attention from the point of view of knowledge and skill empowerment, since they play a leading role in the cultivation and commercialization of food crops.

Recommendation 1.2: Adopt a production ecological approach with a primary focus on identified continental priority farming systems

Although other systems should not be neglected, especially at regional and national levels, to have a significant and speedy impact on agricultural productivity and food security in Africa, four production systems merit priority attention: the maize mixed, the cereal/root crop mixed, the irrigated, and the tree crop based. They represent agricultural bright spots. No generic recommendations can be made to enhance their factor productivity, but systematic production ecological analyses are needed to identify constraints and opportunities for system-specific improvement. The production ecological approach has proven its value in enhancing the productivity of specialized systems and has the capability to unravel the complex relationships in diversified systems. Designing mixed and multiple cropping, as well as multi-dimensional cropping based upon the principles of symbiosis and synergy, should receive greater attention. This should include choice of companion crops, which can extract water and nutrients from the soil and sunlight from the atmosphere in an efficient manner. In general soil fertility and water availability are major limiting factors, but pests



and diseases may reduce productivity growth considerably.

Productivity gains in recent decades in irrigated and commercial agriculture and prospects for further improvements of these specialized systems are favourable and to be encouraged. The bulk of African agriculture is however small-scale, often involving more than 15 crops in combination with animal species in highly diversified, rainfed farming systems. Such systems have received scant attention from science and technology, resulting in limited knowledge of their functioning in ecological, economic and social terms. These shortcomings warrant specific attention to identify opportunities for improvements.

The production ecological approach should also involve the revitalization of the cultivation of ecologically adapted and low-input requiring crops like millets, legumes and tubers, referred to as the local crops of Africa. Both dying wisdom and dying crops need to be saved. This calls for an inter-disciplinary project on under-utilized and orphan crops.

The aim in this strategy is to build on the advantages of diversified crop-livestock farming systems in Africa. Reinforcing the synergies within diversified farming systems in the design and conduct of agricultural research and development is a preferred strategy; specialization by definition does not offer such synergies and is not a panacea. The role of livestock in diversified systems must be recognized and accorded appropriate priority in R&D strategies in response to the increasing demands for animal products in the coming decades. Veterinary extension and services must be strengthened to protect animals against endemic and exotic diseases and zoonoses, and improved genetic stock introduced to enhance animal productivity. The private sector must play a key role here.

Recommendation 1.3: Pursue a strategy of integrated sustainable intensification

The aim of science and technology should be integrated sustainable intensification of agricultural production, encompassing a simultaneous increase in the productivity of land, labour and other inputs, while minimizing adverse environmental effects. The complexity of farming systems in Africa demands integrated approaches. Knowledge-intensive and technology-driven approaches that realize the potentials to boost productivity should be integrated with indigenous knowledge and farmers' needs and demands to assure the appropriateness and adoption of innovations. Integrated soil, water, nutrient and pest management approaches to research



and development, both in the priority and other production systems, are essential for sustainable intensification. This will require local institutional innovations such as farmer field schools promoted by Food and Agriculture Organization, Landcare in Australia, and integrated soil fertility programs of the International Soil Fertility Development Center. New breeding technologies, such as marker-assisted breeding and new biotechnological tools, such as the use of genetically modified organisms (GMOs), are expected to become increasingly important options in addressing the many biotic and abiotic constraints facing African farming systems.

Recommendation 1.4: Bridge the genetic divide

A substantial amount of additional investment is needed to respond to the specific needs of African farmers in order for them to derive benefit from the integrated application of both classical plant breeding and genetic modification. Africa cannot rely on external developments in this field because of the specific requirements of the diversified systems. It would be prudent to adopt a regional rather than a national approach to exploit biotechnology. Without substantial investments now, including by the private sector, Africa will be left behind as biotechnology has a significant gestation period before its impact is realized. Capacity in biotechnology must be strengthened, especially so that public institutions can effectively pursue public-private partnerships to bring the benefits of genetically modified organisms to the orphan crops and neglected areas that constrain African smallholders. The non-GMO components of biotechnology need immediate attention since they can help to improve eco-farming.

As the Green Revolution has largely bypassed marginal regions (which are extensive on the African continent), life sciences should focus especially on traits such as drought tolerance and resistances to the wide variety of pest and diseases. Greater attention should be given to breeding for agro-ecological and farming system niches using decentralized breeding and farmer participatory breeding approaches. Both research capabilities and regulatory procedures will need strengthening in order to exploit these opportunities in life sciences and ensure that biosafety aspects are adequately addressed. The well-being of farmers and consumers and the safety of the environment should be the bottom-line of the regulatory policies.



Recommendation 1.5: Recognize the potential of rainfed agriculture and accord it priority

Rainfed agriculture will remain the dominant system in Africa for decades to come. The further scope for economically viable and environmentally benign large-scale irrigation development in Africa is limited. Rainfed systems offer the best opportunities for the improved productivity that reduces poverty and food insecurity, provided there are greatly increased investments in agricultural research and development and infrastructure directed at these agro-ecologies.

Large improvements in water-use efficiency can be obtained in rainfed production systems by exploiting ecological synergies. A comprehensive package of agronomic measures should be pursued, including drought-tolerant cultivars; fertilization and small-scale supplemental irrigation during prolonged drought periods; harnessing underground water, even if quality is poor; or rainwater harvested in small dams. Supplemental irrigation can prevent total crop failure and stabilize and improve crop yields, but it is only likely to be profitable on higher-value crops. Inclusion of risk-reducing information with weather forecasts should be an integral part of such a comprehensive strategy.

Recommendation 1.6: Reduce land degradation and replenish soil fertility

Soil health and fertility management holds the key to enhancing crop productivity. Land degradation, due to overexploitation through cultivated area expansion, is a major threat to the African continent and leads to a downward spiral of productivity. This spiral can be broken with an integrated approach, exploiting the synergistic effect of inorganic and organic fertilization on soil and crop productivity. Low external input agriculture appears inadequate to control nutrient depletion, and to increase labour productivity. It should be realized that the very poor fertility of many African soils requires a long-term investment, which may not be forthcoming if relying only on market forces.

Recommendation 1.7: Explore higher-scale integrated catchment strategies for natural resource management

Strategies on catchment/watershed scales should be explored to optimize land and water use and safeguard biodiversity. This should include management of forest resources and conservation of native vegetation and associated wildlife habitat.



The projected water scarcities in many regions of Africa require strategies and policies for its sustainable use to address the increasingly competitive multi-sectoral demands for water. Appropriate combinations of legal frameworks, education and social mobilization will be required to build a sustainable water security system for Africa.

Recommendation 1.8: Promote the conservation, sustainable and equitable use of biodiversity

Africa has a rich treasure trove of biodiversity in flora and fauna. In many circumstances, properly structured private-public sector partnerships can provide a means of exploiting this potential and creating niche markets (e.g., medicinal plants). Increased investments in national and regional genebanks will be required to fully realize this promise. Tools need to be developed to determine the value and function of the different components of agrobiodiversity to farmers and other sectors of society if it is to be conserved and sustainably used. As well, conservation and commercialization have to become mutually reinforcing so as to create an economic stake in conservation.

To give effect to this will require a strengthening of local, national and subregional policies on agrobiodiversity conservation and use. Policy support is vital to halt genetic erosion; without it, national programs will continue to lack the finances and capacity to support conservation and use initiatives in a meaningful way. As a first step, make information on agrobiodiversity known and readily available in different formats for different audiences and users. In areas rich in the biodiversity of under-utilized crops like sorghum and millets, as for example in the Rift Valley in East Africa, community-managed agrobiodiversity sanctuaries may be established.

Recommendation 1.9: Enhance use of mechanical power

Selective mechanization to increase power-use intensity is an important option where there are labour shortages for specific operations and no adverse environmental consequences. Such an option would improve labour productivity; facilitate timeliness of operations, especially with the increasing labour constraints arising from health-related problems (such as malaria, TB and HIV/AIDS); and reduce drudgery. This would also reduce the dependence on hand-tools in favour of animal and mechanical draught power, which may also serve to attract currently disaffected youth to consider farming as a worthy career.



There is a need to encourage at national and regional levels the local manufacture of agricultural inputs, including agricultural machinery and equipment for all phases of agricultural production, fertilizer, agricultural chemicals, etc., in order to enhance agro-industrial development and reduce African countries' dependence for such goods on the industrialized countries of the world.

Recommendation 1.10: Embrace information and communication technology at all levels

Information and communications technology tools, such as decision-support systems and geographic information systems, should be mobilized to help amplify, accelerate and improve the precision of farmer decisionmaking and harvest the fruits of modern methods such as integrated water, nutrient, pest and disease management and weather forecasting information. Information and communications technology can also be used at catchment levels to investigate emerging issues that arise from increased competition for water within agriculture, and between agriculture and other sectors.

To realize these opportunities to reach the unreached and excluded, there must be vastly improved access to information and communications technology in Africa. Increased investments in communications and knowledge infrastructure are required to enable access to the Internet, libraries and information centres for the participatory knowledge quadrangle of farmers, extension professionals, educators and scientists. Such investments will provide them with the resources of currently available databases and other information. Institutions lacking fast and affordable access to the Internet should make full use of CD-based information sets such as The Essential Electronic Agricultural Library. Better-connected institutions should subscribe to Access to Global On-Line Research in Agriculture. There is also significant potential for web-based distance education and videoconferencing to both complement and supplement courses given in African universities. An integrated application of the Internet and radio will help to transmit timely information to all who may benefit from it.



Recommendation 1.11: Improve the coping strategies of farmers in response to environmental variability and climate change

Climate change and variability highlights the necessity to develop anticipatory short- and long-term forecasting research, and this requires training of scientists. Severe constraints in African agriculture are the high risk of crop failure and death of animals due to variability in weather, particularly rainfall. These constraints will be exacerbated by climate change. Addressing them requires a comprehensive set of agronomic measures, including drought-tolerant crops and supplementary irrigation. Crop improvement strategies should place greater emphasis on robust systems that reduce yield losses due to extreme weather events and greater consideration should be given to changing crop species (e.g., replacing some maize with cassava in Southern Africa).

2. Building impact-oriented research, knowledge and development institutions

Recommendation 2.1: Design and invest in national agricultural science systems that involve farmers in education, research and extension

A paradigm shift is needed towards an innovation, information, knowledge, and education quadrangle coalition in place of the outmoded linear and top-down research-extension-farmer-framework that has failed in Africa. Institutional arrangements to achieve this may differ from country to country and each must be encouraged to learn from its own experiences. There is a need to start from the bottom up in developing rural knowledge systems and institutions using participatory methods. There is also a need for substituting traditional extension systems with farmer participatory knowledge systems that are more gender sensitive. Community-based farmers' organizations must be established more widely and existing ones strengthened to facilitate the development of such farmer participatory knowledge systems and to promote value addition, agro-processing and marketing that can better exploit economies of scale and encompass vertical, horizontal and lateral integration from production to markets. There is a pivotal role to be played by the International Service for National Agricultural Research in action research, designed to distill from the experiences of national agricultural research systems everywhere best practice options to guide this process.



The pay-off to investment in agricultural science and technology will be higher if planning and investments are coordinated and sequenced. Design of organizational structures should promote ‘connectivity’ between the complementary institutions and a reward structure that encourages managers, scientists, farmers and credit institutions to communicate and cooperate with each other. Connectivity should include closer cooperation between university faculty members and their students working with national agricultural research scientists on priority problems of mutual interest. This will not only add university resources to technology-generating research efforts but will also improve the relevance, realism and quality of students’ thesis research and overall educational experience. Farmer science and training centres are required that use farmer field schools and hands-on training to impart technical skills to farmers and their children in a learning-by-doing mode. This would be a part of a farmer participatory knowledge system within the participatory knowledge quadrangle coalition.

The Sub-Saharan Africa Challenge Program has many of the elements required to give effect to this paradigm shift and is to be encouraged. However, high transaction costs are a cause for concern. Of course the expectation is that the Challenge Program will open new funding windows, but the jury is still out on this.

Recommendation 2.2: Encourage institutions and mechanisms to articulate S&T strategies and policies

National governments, subregional and continental agencies should formulate sectoral and multi-sectoral strategies and policies that recognize the importance of agriculture and agricultural science and technology to improving productivity and food security and accord to these the appropriate priorities. These should build upon the national agricultural research systems, subregional organizations, FARA and NEPAD processes and involve the private sector. Academies of science should be encouraged to develop mechanisms to more effectively articulate s&t strategies and policies and become more relevant to the achievement of national goals. National s&t Councils for Food and Agriculture should be formed with well-defined mandates and adequate budgets to give effect to agreed national agricultural R&D strategies and priorities. Such Councils would comprise representatives from users and creators of knowledge and technologies, as well as from relevant government ministries, including agriculture, science and technology, food, trade, industry and finance.



To maximize the synergies in achieving food security and reduce vulnerability to shocks, a coordinated multi-sectoral strategy is needed, including health (hygiene, sanitation and safe drinking water); education; and agricultural/rural planning and development. There is a particular need to recognize the key role of women's education and status in reducing child malnutrition, the most insidious form of malnutrition. The Poverty Reduction Strategy Papers should embrace such strategies: to date there is little evidence of their inclusion. Strategies should include pro-active partnerships between the private sector and public research and extension agencies and, where improved efficiency and effectiveness could be achieved, privatization of public sector extension.

For the short term, an integrated package of appropriate technology options, services, and public policies, particularly in the field of input and output pricing and information, is needed to close yield gaps and move technologies from the shelf to the field. Technologies on the shelf are often not necessarily sufficiently tailored. In some cases adaptation and fine-tuning of technology options will be required (for example, conferring insect resistance to maize and cotton cultivars using genetically modified organisms, as in South Africa). The private sector can play a significant role here. In the longer term, national, regional and continental strategic research capacities need strengthening to increase productivity potentials. Further research on technology exchange and delivery systems is also required.

Recommendation 2.3: Cultivate African centres of agricultural research excellence

The establishment of African centres of agricultural research excellence (ACARE) would enable research on both continental and regional strategic priorities as complements to national agricultural research systems (NARS). These would evolve from and build upon existing national agricultural research institutes, international agricultural research centres and university programs through strategically targeted institutional capacity-building investments, and would not normally involve the creation of another layer of new institutions or bricks and mortar. Such institutions would be virtual centres of excellence, with a concentration of researchers and programs with guaranteed finances and output quality control through international upgrading and updating mechanisms. These virtual centres would be African owned and governed, provide a magnet for African scientists to remain at home, and help strengthen African national agricultural research



systems. A possible model for these is the Cooperative Research Centre (CRC) program in Australia. ACARE will require new and assured funding mechanisms and the CRC offers one approach. Others are explored in the recent InterAcademy Council (IAC) report *Inventing a better future*. NEPAD, FARA and the African subregional organizations should be directly involved in the design and development of the ACARE concept.

Immediate candidates for ACARE research foci might include biotechnology, climate change, biodiversity and post-harvest technology. Programs within CGIAR centres could be core elements or foundations for the ACARE. There is also good scope for the private sector to collaborate and lend support. In many cases, virtual ACARE may evolve from CGIAR centres, for example in biotechnology. ACARE can help address the NARS fragmentation challenge, ensure critical mass and facilitate linkages with international agricultural research centres and advanced research institutions in the North and South. Indeed the latter may be even more relevant to Africa. Clear criteria and mechanisms for the establishment of ACARE will need to be developed; the IAC report also contains useful guidelines in this respect. The InterAcademy Council, the InterAcademy Panel (IAP), and the academies of science could play a role in identifying suitable candidates for ACARE.

Regional research networks should evolve progressively from instruments of information exchange into entities that promote enhanced collaboration among various research partners, including the private sector, in pursuit of agreed priority regional research programs. Competitive research funds and matching grants could provide a mechanism for this.

Recommendation 2.4: Increase support for agricultural research and development

Governments and donor agencies must recognize that building impact-oriented institutions requires sustained and sizeable increases in the support of agricultural research and development that involve both institutional core funding as well as competitive grant provisions. To capitalize on the demonstrated high returns to agricultural research and development in Africa and its unique role in enhancing productivity and food security and reducing poverty across all the heterogeneous production systems, agricultural research funding to national agricultural research systems should increase in real terms by at least 10 percent per year to 2015. This would double the agricultural research investment on average to at least 1.5 per-



cent of agricultural GDP. As a quid pro quo for increased investments, agricultural R&D institutions must accept more stringent monitoring, evaluation and impact assessment to improve accountability and credibility and to become more flexible and responsive learning institutions. Without increased public investment in agricultural research and development, the private sector will remain moribund.

Africa's agricultural science community cannot flourish if it continues to depend upon foreign aid for around 40 percent of its budget. Within national agricultural research systems, this means implementing one or more of the following: generating some revenues through producer levies, pursuing contract research, devolving some commodity research programs to producer groups where feasible, forming alliances with private sector entities and generating revenue from the commercialization of research products and services.

Recommendation 2.5: Strengthen international agricultural research centres

The international agricultural research centres with headquarters and/or programs in Africa should retain their international identities, but operate in more collaborative and complementary modes with national agricultural research institutes and universities in Africa, and in participatory partnership with farmers and consumers. They should immediately integrate their programs at the operational level, in ecoregional consortia, in order to ensure critical mass and to exploit economies and synergies. In this manner they will be more responsive to African priorities. The scope for full institutional integration should be explored by the CGIAR as a matter of priority. They would phase out of applied and adaptive research activities for which national institutions are more cost effective, and develop comparative advantages in those basic and strategic research activities that enjoy economies of scale, require larger investments and for which there are broad global and continental research spillovers.

These African-based international agricultural research centres would provide the proposed African centres of agricultural research excellence with opportunities for improved access to international public S&T goods as peers. The level of investment in the African CGIAR centre programs for research and capacity building should be progressively strengthened by at least 5 percent per year, to at least US\$235 million by 2015.



3. Creating and retaining a new generation of agricultural scientists

Recommendation 3.1: Focus on current and future generations of scientists in Africa

A greater effort must be made to retain current and future generations of African scientists to reduce the brain drain, rather than trying to regain the current African scientific Diaspora. This can be done by implementing policies that create more personally and professionally rewarding scientific opportunities in Africa. This will require competitive levels of compensation, opportunities to advance professionally based on rigorous but fair and transparent evaluation systems, well-equipped laboratories, access to current global sources of scientific information, and adequate operating funds. Professional growth funds should be available to actively encourage and enable young scientists to attend international conferences, summer institutes in Africa conducted by renowned professors, workshops and seminars in order to enhance their professional competence and self-confidence by interactions with peers.

There is scope for effective and efficient capacity building and strengthening the involvement and commitment of advanced research institutions and organizations by 'sandwich programs,' institutional twinning and visiting scientist arrangements using the proposed African centres of agricultural research excellence and advanced research institutes. Professional associations of agricultural scientists should be strengthened and encouraged to develop in Africa and to become more politically aware and constructive policy advocates. To stimulate professionalism, it has become essential that codes of conduct/ethics are developed and enforced by the professional associations as a condition of membership. In an era of expansion of the scope of intellectual property rights and genetic engineering, and marketing of proprietary products (e.g., pesticides and biochemicals), this has now become an urgent need.

The number of young scientists completing overseas graduate programs and returning home to pursue careers in national institutions can be increased if on arrival they have access to modern scientific infrastructure, information and communications technology (ICT), adequate research funding, and attractive monetary and non-monetary incentives. The ICT private sector could be especially helpful in this respect. To enhance the professional motivation and social recognition of agricultural scientists in the national agricultural research systems and universities, a professional



career service is required to provide recognition and reward for outstanding and innovative scientists. Leadership training should be a feature of the career services. The scientific infrastructure for effective and lasting academic partnerships includes post-degree networking and mentoring. Start-up research grants and a clear career path are key elements in a strategy to reduce further brain drain. The priority aim would be to cultivate young African scientists rather than expect senior academics and researchers to leave the Diaspora and return permanently to Africa.

Recommendation 3.2: Broaden and deepen political support for agricultural science

Real improvement in agricultural education and research requires strong support from top political leaders. A coalition of supportive agricultural constituencies must be formed, including farmers associations, producer groups, national agribusiness companies, educators and researchers. Deans of agricultural faculties and directors of research must become more politically savvy and entrepreneurial, building political support among farmers, government ministers and donors. The international agricultural research centres, such as International Service for National Agricultural Research (ISNAR) could assist this process by provision of leadership and media communications training.

Recommendation 3.3: Reform university curricula

To improve the effectiveness of agricultural scientists, the undergraduate curricula of agricultural universities should also stress production ecological and multidisciplinary approaches to better prepare them for the innovation, information, knowledge and education quadrangle. Students should be better sensitized to the socio-economic and policy environments in which agricultural development occurs and in which they will be working during their careers, including the role of gender. Virtual universities and colleges on a regional basis could be resource centres for such a pedagogic revolution to better prepare students to collaborate with colleagues in related fields and to competently bridge the gaps separating farmers, educators, researchers and extensionists. The aim would be to supplement narrow disciplinary-based 'bamboo' graduates with more holistic 'baobab' graduates with a problem-solving focus. Field research work with farmers using participatory approaches, exposure to indigenous knowledge sys-



tems and linking them to modern science, would be of great value in many areas. Strong training in information and communication technology is essential. Disciplinary specialists will continue to be required for the strategic research challenges of the future. These skills will be primarily developed at post-graduate levels.

Recommendation 3.4: Mobilize increased and sustainable funding for higher education in science and technology, minimizing dependence on external donor support

Curricula reform, improving faculty and scientist compensation, and modernizing teaching and research infrastructure are expensive, and require stable funding over time. Lasting improvements in higher education in the agricultural sciences must ultimately be funded from national resources.

There is an urgent need for increased investment in and enhancement of both the numbers of students and quality of agricultural education (i.e. science, food, processing, natural resource management, rural development) at primary, secondary and tertiary levels. The international financial institutions, United Nations and bilateral agencies should play a particularly important role in this revolution in education. The African Land Grant University model may need to be reinvented as part of this, with the focus on strengthening and adapting existing universities rather than creation of additional ones.

African educators need to become much more familiar with experiences in educational reform throughout the world, particularly in Asia and Latin America. But models used elsewhere can rarely be imported successfully. Rather they need adaptation to fit local political, social, institutional and economic environments. Participatory planning and close monitoring to guide mid-term corrections are essential. Human and institutional capacity building is a gradual and often incremental process that takes time to have real impact.

There is good scope to explore the potential for efficiencies in regional graduate training models. The large number of small countries in Africa means it is often difficult for individual universities to achieve a critical mass of teachers in specialized areas such as biotechnology. Appropriately designed regional training approaches may provide a solution. However, rather than creating new regional institutions, self-initiated efforts—building ‘regional specializations’ within existing universities and then developing networked training programs that attract students from a regional wa-



tershed – are generally more successful. Such initiatives may initially rely on external support for design, launch and fine-tuning, but must generate adequate national or regional resources to be sustained over time. They must be professionally competitive with global training alternatives; they must have strong buy-in and commitment for regional cooperation from a critical mass of partner universities; and they have to do business in a fully transparent, apolitical, unbiased and accountable manner.

Because of greater relevance, lower cost, less attrition and the residual long-term benefits of strengthening national institutions, priority should ideally be to provide graduate training in African universities whenever competitive programs exist. Foreign degree programs should generally be reserved for highly specialized areas where competitive programs have not yet been developed. Sandwich-training approaches, already alluded to in Recommendation 3.1, should be adapted where appropriate – to lower costs, increase the relevance of thesis research and to increase graduate returnee rates. The international agricultural research centres in Africa already provide opportunities for thesis research.

Recommendation 3.5: Strengthen science education at primary and secondary school levels

An essential base on which to support the emergence of future generations of agricultural scientists, educators and indeed farmers, is stronger science training from the start. Improved curricula focusing on agriculture, and combining the best of modern and indigenous scientific knowledge, can help attract the brightest young Africans into the agricultural sciences and farming. A special emphasis must be placed on improving the accessibility and friendliness of science training to young women. Farm science schools where the pedagogic methodology is ‘learning by doing’ are urgently needed for the knowledge and skills empowerment of semi-literate and illiterate farmers.

4. Markets and policies to make the poor income and food secure

Recommendation 4.1: Increase investments in rural infrastructure

Governments need to increase investments in infrastructure such as roads, information and communications technology, storage, post-harvest



technology, and value addition, and ensure the appropriate grading standards, sanitary and phytosanitary regulations are in place and enforced. Unless this is done, neither producers nor consumers will derive full benefit of enhanced production.

Recommendation 4.2: Strengthen capacity to expand market opportunities

Regional cooperation is required to remove formal and informal barriers to trade, strengthen the contract system, establish food quality and food safety standards and increase research capacity in all these areas. Such cooperation can promote interregional trade within Africa and widen international market opportunities, which can provide a floor to commodity prices as agricultural productivity and marketable surpluses increase. There is a need to open up diversified market opportunities in concert with the private sector, including non-food commodities, to promote food self-reliance and security. To strengthen the competitive ability of African farmers, appropriate advanced market intelligence and logistics are required, along with land-use planning.

Recommendation 4.3: Institute effective intellectual property rights regimes to encourage the private sector and facilitate public-private partnerships

If the benefits of modern science and technology are to reach African smallholders it will be important to pay attention to issues of intellectual property rights (IPR). Resource-poor farmers will be excluded from the benefits of modern science, including biotechnology, if specific measures are not taken to avoid social exclusion in the dissemination of new technologies. In cases of patented technology developed by the private sector, suitable institutional devices should be developed by governments, with financial support from multilateral and bilateral donors, for purchasing such technology options and making them available to the national agricultural research systems and smallholder farmers. Models include the African Agricultural Technology Foundation (AATF). Unless mutual trust and dialogue occur, public-private partnerships will remain elusive.

In developing policies in intellectual property rights it is important to provide a mechanism for recognizing and rewarding the contributions of African rural women and men to the conservation and enhancement of in-



digenous agro-biodiversity. The policy should be designed to stimulate inventions and innovations relevant to the needs of the rural poor and to foster food, nutrition and health security for all. The IPR policy should be gender sensitive, since women play a leading role in the selection and conservation of plant genetic resources.

Recommendation 4.4: Reduce barriers to increased African trade with OECD countries

Improved international market access will be a key ingredient in translating increases in African agricultural productivity into improved food security. Current trade negotiations should recognize this. OECD countries should allow developing countries more access to their markets and reduce their domestic agricultural subsidies and tariff/non-tariff barriers to trade. They should also assist developing countries to meet quality, safety and sanitary/phytosanitary standards, and help to improve their negotiation and decisionmaking abilities through collaborative research and capacity building. Africa should not replicate OECD trade and protection policies as a general countervailing response. But to catalyze African agriculture, there should be scope for such things as targeted subsidies for strategic inputs, such as biological and mineral fertilizers, making use of the successful voucher systems that were used in various programs of the International Centre for Soil Fertility and Agricultural Development (IFDC). Public policies should also incorporate safety nets to address risks and nutrition security, as well as payments to farmers for environmental services.

Recommendation 4.5 Improve data generation and analysis related to agriculture, food and nutrition security, and vulnerability

There are major constraints to the analysis of productivity trends and their determinants and the design of appropriate strategies and policies for science and technology. The constraints include the lack of quality statistics on agricultural production, food and nutrition status, and the extent of vulnerability to uncertain events on a disaggregated agroecological and sub-national basis. There are also special problems related to the heterogeneous diversified production systems of Africa, and staff members of statistics offices require continuous research and training. The FAO, with WHO and UNICEF, should take the leadership in this endeavour and design strategies and scientific methodologies to ensure in future that such data are free of political influences.



5. Engaging science and technology for the benefit of African agriculture in the near term

Recommendation 5.1: Employ the Study Panel's recommended strategies to implement a series of Participatory Science and Technology Pilot Programs

The Study Panel's recommended strategies should be employed to implement a series of Participatory Science and Technology Pilot Programs, focusing on the priority continental farming systems identified by the Study Panel and on institutional innovations that aim to realize unexploited yield potentials, thereby improving food security. As described in this report, the Study Panel undertook a priority assessment of 10 major African farming systems, using two indicators – an agricultural value-added index and a composite underweight children index. Based on this analysis, four priority farming systems were identified: maize mixed, cereal/root crop mixed, irrigated, and tree crop based. The highland farming systems were not fully represented in this analysis, and they may also have potential. For all these farming systems, there are many technological opportunities for enhancing productivity and profitability in Africa on an environmentally sustainable basis

As 'seeing and harvesting are believing' to resource-poor farming families, the Study Panel proposes the following action agenda:

- a. The initiation of Participatory Science and Technology Pilot Programs should be initiated, which can develop appropriate s&t institutional innovation options for unleashing latent productivity potentials, leading to an enhancement of household food and income security. There is a need for operational-scale pilot s&t programs covering small agro-ecological regions. These area-level multi-institutional programs could be developed for the four 'best bet' continental priority farming systems areas and/or priority systems identified regionally or nationally.
- b. The UN Secretary-General should take steps to identify appropriate regional, national and international institutions to implement the pilot programs designed to shape Africa's agricultural future. There should be strong African involvement at every step.
- c. Such participatory s&t pilot programs should be introduced where the following components of the production-processing-marketing-consumption chain can be developed in a participatory mode:
 - An assessment of indigenous technology options relevant to improvement of productivity and food security;



- An assessment of market potentials and constraints for existing and prospective commodities in the farming systems;
- An assessment of the scope for the following new technology options to enhance productivity and food security:
 - › Integrated nutrient and soil fertility enhancement;
 - › Integrated pest management;
 - › Small-scale water harvesting and efficient and economic use through micro-irrigation systems of delivery of water and nutrients;
 - › Biotechnological applications like improved genetic strains (including genetically modified organisms, where relevant), biofertilizers and biopesticides;
 - › Use of improved farm implements and appropriate mechanization for increasing labour productivity, reducing drudgery and ensuring timely farm operations;
 - › Introduction of appropriated post-harvest processing, storage and marketing techniques;
 - › Promotion of non-farm employment through the introduction of technology options for adding economic value to primary products and through agri-business enterprises based on micro-credit;
 - › An information and communication program to provide location-specific information relating to meteorological, management and marketing factors and to promote genetic, quality and trade literacy among smallholder rural farm families;
 - › Establishment of farmer field schools for integrated pest, disease and weed management, integrated water and fertility management and the other aspects of production and post-harvest technologies based on the principle of learning by doing;
 - › Promotion of institutional structures like cooperatives and self-help groups that can confer the power of scale to smallholders at the production and post-harvest phases of farm operations.
- Exploring the scope for institutional innovations such as:
 - › The promotion of a participatory knowledge quadrangle coalition led by smallholders involving them and universities, national agricultural research institutions and extension agencies to explore new modes of partnership;
 - › The identification of candidates for African centres of agricultural research excellence that would serve the interests of smallholders;
 - › The stimulation of public-private partnerships that would address priority constraints that cannot be alleviated by independent activi-



- ties and aimed at building trust and synergies;
 - Identifying the constraints at the national, regional, continental and global levels that prevent the realization of the promise and potential of the Participatory Science and Technology Pilot Programs to improve agricultural productivity and food security at the local level.
- d. The Study Panel suggests that interdisciplinary teams from the quadrangle of national agricultural research systems, universities, extension services and farmers' organizations be constituted to prepare business plans for policy changes and research in priority farming systems. Nothing succeeds like success, and hence the sites for the initial pilot schemes should be developed where there is a socioeconomic, political, scientific and ecological environment conducive to the achievement of the goals of this program. A local farmers' advisory council involving both men and women should be constituted to assume ownership and undertake monitoring and evaluation of the program.
- e. Within the pilot schemes, plans should be developed that stimulate convergence and synergy among the range of programs designed to achieve the following UN Millennium Development Goals:
- Eradicate extreme poverty and hunger through a paradigm shift from unskilled to skilled work and through sustainable farming systems intensification, diversification and value-addition;
 - Achieve universal primary education;
 - Promote gender equality and technological and skill empowerment of women;
 - Improve maternal health and nutrition, so as to avoid the birth of babies characterized by low birth weight;
 - Combat HIV/AIDS, malaria and other diseases;
 - Ensure conservation and enhancement of basic life-support systems (i.e., land, water, forests, biodiversity and the atmosphere).
- f. To mobilize the necessary technological, financial, managerial and institutional resources essential for the successful implementation of these pilot programs – designed to harness the best in frontier science and traditional wisdom for enhancing the productivity, profitability and sustainability of major farming systems – it is necessary to organize local- or regional-level consortia or coalitions of farmers, government, nongovernment, community, research, educational, mass media and financial and donor institutions. The Participatory Science and Technology Pilot Programs should not draw resources from existing programs, but build upon them.
- g. These pilot programs should entail action research. There will need to



be an effective monitoring and evaluation capability to assess their performance and draw appropriate lessons for designing operational programs which involve upscaling and adaptation to the diverse environments in Africa.

Table 8.1. Target audiences and time frames for impact of strategic recommendations

Strategic recommendations	Target audiences								Time frame for initial impact (yrs)			
	National governments	NARS ¹ & university managers	Private sector	Subregional organizations	FARA ²	NEPAD ³	International agencies	OECD/donors	CGIAR ⁴ / IARC ⁵ /ARI ⁶	Near term <5	Medium term 5-10	Long term >10
	1. SCIENCE AND TECHNOLOGY OPTIONS THAT CAN MAKE A DIFFERENCE											
1.1 Adopt a market-led productivity improvement strategy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
1.2 Adopt a production ecological approach with a primary focus on identified continental priority farming systems	✓	✓		✓	✓	✓	✓	✓	✓	✓		
1.3 Pursue a strategy of integrated sustainable intensification	✓	✓		✓	✓	✓	✓	✓	✓	✓		
1.4 Bridge the genetic divide	✓	✓	✓	✓	✓	✓		✓			✓	
1.5 Recognize the potential of rainfed agriculture and accord it priority	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
1.6 Reduce land degradation and replenish soil fertility	✓	✓		✓	✓	✓	✓	✓	✓	✓		
1.7 Explore higher scale integrated catchment strategies for natural resource management	✓	✓		✓		✓	✓	✓	✓			
1.8 Promote the conservation, sustainable and equitable use of biodiversity	✓	✓		✓	✓	✓	✓	✓	✓			✓
1.9 Enhance use of mechanical power	✓	✓	✓			✓				✓		
1.10 Embrace information and communication technology at all levels	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
1.11 Improve the coping strategies of farmers in response to environmental variability and climate change		✓						✓			✓	
2. BUILDING IMPACT-ORIENTED RESEARCH, KNOWLEDGE AND DEVELOPMENT INSTITUTIONS												
2.1 Design and invest in national agricultural science systems that involve farmers in education, research and extension	✓	✓	✓			✓				✓		
2.2 Encourage institutions and mechanisms to articulate S&T strategies and policies	✓	✓		✓	✓	✓		✓		✓	✓	✓
2.3 Cultivate African centres of agricultural research excellence	✓					✓					✓	
2.4 Increase support for agricultural research and development	✓						✓	✓		✓		
2.5 Strengthen international agricultural research centres							✓	✓	✓		✓	

1 NARS: National agricultural research system
 2 FARA: Forum for Agricultural Research in Africa
 3 NEPAD: New Partnerships for Africa's Development
 4 CGIAR: Consultative Group on International Agricultural Research
 5 IARC: International agricultural research centre
 6 ARI: Advanced research institute

Strategic recommendations	Target audiences									Time frame for initial impact (yrs)		
	National governments	NARS ¹ & university managers	Private sector	Subregional organizations	FARA ²	NEPAD ³	International agencies	OECD/donors	CGIAR ⁴ / IARC ⁵ /ARI ⁶	Near term <5	Medium term 5-10	Long term >10
3. CREATING AND RETAINING A NEW GENERATION OF AGRICULTURAL SCIENTISTS												
3.1	Focus on current and future generations of agricultural scientists	✓	✓						✓		✓	
3.2	Broaden and deepen political support for agricultural science	✓	✓	✓	✓	✓	✓			✓		
3.3	Reform university curricula	✓	✓									✓
3.4	Mobilize increased and sustainable funding for higher education in S&T, minimizing dependence on donor support	✓	✓				✓	✓		✓	✓	
3.5	Strengthen science education at primary and secondary school levels	✓	✓									✓
4. MARKETS AND POLICIES TO MAKE THE POOR INCOME AND FOOD SECURE												
4.1	Increase investments in rural infrastructure	✓					✓	✓	✓	✓		
4.2	Strengthen capacity to expand market opportunities	✓					✓	✓	✓	✓		
4.3	Institute effective intellectual property rights regimes to encourage the private sector and facilitate public-private partnerships	✓					✓	✓	✓		✓	
4.4	Reduce barriers to increased African trade with OECD countries								✓	✓		
4.5	Improve data generation and analysis related to agriculture, food and nutrition security, and vulnerability	✓						✓		✓		
5. ENGAGING SCIENCE AND TECHNOLOGY FOR THE BENEFIT OF AFRICAN AGRICULTURE IN THE NEAR TERM												
5.1	Employ the Study Panel's recommended strategies to implement a series of Participatory Science and Technology Pilot Programs	✓	✓	✓	✓	✓	✓	✓	✓	✓		

Note: The strategic recommendations are not arranged in a priority sequence. Rather the complete set of recommendations are regarded by the IAC Study Panel as an operational strategy that needs to be implemented in its entirety.



Annex A. Priority issues that emerged from African regional consultative workshops

The IAC Study Panel conducted a series of joint consultative African regional workshops, in association with subregional organizations, during January and February 2003. Summary proceedings of these four workshops are accessible from the IAC website, www.interacademycouncil.net. Sponsors, dates, location, and participant numbers for the four workshops follow:

- Eastern and Central Africa (Association for Strengthening Agricultural Research in Eastern and Central Africa/InterAcademy Council (ASARECA/IAC)), 31 January-2 February 2003, Inter-Continental Hotel Nairobi, Kenya; 43 participants.
- Northern Africa (Association of Agricultural Research Institutions in the Near East and North Africa (AARINENA)/IAC), 3-5 February 2003, Hassan II Institute of Agronomy and Veterinary Medicine, Rabat, Morocco; 30 participants.
- Southern Africa (National Department of Agriculture, Republic of South Africa/IAC), 7-9 February 2003, Magaliesburg, South Africa; 32 participants.
- Western and Central Africa (Le Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles (CORAF)/IAC), 10-12 February 2003, Dakar, Senegal; 45 participants.

The aims of the workshop were twofold: (1) understand the regional constraints to improved agricultural productivity as a means of improving food security; and (2) identify explicitly the role of science and technology (s&t) in alleviating constraints and exploiting opportunities.

Following are the priority issues that emerged from the regional consultative workshops. It should be noted that the listing does not imply any particular order of priority by the Study Panel. It represents the predominant views of those attending the consultative workshops.

Institutional issues

Markets

- Prices for outputs of smallholders are too low and those of inputs too high, such that their ability to become more market-oriented is severely constrained.



- Paucity of access by smallholders to market, technology and other information means missed opportunities. There is need to capitalize on the unique opportunity provided by information and communications technology to provide such access.

National agricultural research systems and subregional organizations

- There is inadequate intersectoral strategic planning and priority setting for agricultural research and development (R&D) on both a national and regional basis.
- At best there are weak linkages between national agricultural research institutes and the universities, and often they are non-existent; this represents a failure to exploit synergies when there are acknowledged human and financial constraints to effective agricultural research and development in the national agricultural research systems (NARS).
- Collaboration among the NARS, subregional organizations, international agricultural research centres and the advanced research institutes needs to improve significantly in order to fully exploit synergies.
- There have been excessive and continuous reforms and restructuring of NARS, with different approaches being suggested by different donors. Decentralization/devolution and increased stakeholder participation offer many attractions but also pitfalls.

Farmers

- There are inadequate numbers of effective smallholder farmer organizations to ensure their full participation as key stakeholders in national, regional, continental and international agricultural R&D priority setting.

Governments

- The quality and extent of science education at primary, secondary and tertiary levels is inadequate, which limits capacity building. A major boost in the priority accorded to science education at all three levels is required.
- There are weak or non-existent links between research and extension. There is a rejection of the linear model of the research-extension-farmer linkage and an expressed need for a fresh approach.
- Customary and communal land tenure systems are often poorly developed and as a result are constraining investments in agriculture by smallholders, especially in some countries of Southern Africa.



Private sector

- There are a limited public-private partnerships in agricultural research and development, which could be helped by investing in basic communications and transport infrastructure, as well as cultivating a climate of trust between the two sectors that is currently lacking.

The policy environment

Markets and trade

- Globalization and subsidies by countries in the Organization for Economic Co-operation and Development (OECD) are placing undue challenges and constraints on African countries in pursuing an export-oriented agricultural marketing strategy. African countries will need to develop more effective international advocacy with the North, perhaps on a regional basis.
- Barriers are limiting African intra-regional trade opportunities countries must harmonize their intra- and inter-regional trade policies.
- Domestic agricultural markets are not functioning effectively due to poor infrastructure and inadequate availability of timely market information.

Resources and governance

- There are inadequate incentives for the private sector to invest in the agricultural sector, resulting in underinvestment and capital flight.
- Poor governance is leading to a breakdown of the democratic institutions that are critical to a more participatory involvement of stakeholders in agricultural R&D agenda setting and resource mobilization.

Science and technology strategies

Constraints and opportunities

- Soil, water and fertility management represent key natural resources constraints; addressing these will require local, national and regional research and/or policy interventions, depending on the nature and extent of the particular constraints.
- Loss of genetic diversity of wild and domesticated flora and fauna requires enhanced conservation strategies, community participation, application of biotechnology, and capacity building.
- Sustainable food security is jeopardized by health issues, such as poor nutrition and/or diseases such as HIV/AIDS, malaria and TB, leading to



loss of human capital among farmers, scientists and their families.

- The relative economic and environmental merits of large-scale compared to small-scale irrigation development remains an open question, and an appropriate strategy for irrigation development in the various agro-ecological zones of Africa is unclear.
- Is there sufficient agricultural technology 'on-the-shelf' to increase agricultural productivity if only the policy regimes and infrastructure were conducive to adoption, or is more innovative research needed to identify viable productivity-enhancing technology options for the complex diversified agricultural systems of Africa?
- Should Africa embrace genetically modified organisms (GMOs) and the associated biosafety protocols, as a desirable component of a strategy that aims to substantially improve productivity potentials of the major food and commercial crops and livestock species?

Markets

- There is a need to adopt a proactive regional approach both to participation in the establishment of quality and phytosanitary standards associated with access to markets of OECD countries and in international conventions (desertification, climate change and biodiversity).
- The lack of an effective intellectual property rights regime especially hampers R&D activities of the private sector and reduces investment by both national and international firms.

Capacity

- Weak and/or non-existent national academies of science and professional associations reduce the influence of scientists in the formulation of S&T strategies and policies and the mobilization of resources for agricultural research and development.

Planning and incentives

- There is a need to articulate more coherently national S&T strategies and policies that integrate across sectors. Subregional organizations are reluctant and/or unable to enter into the political arena in a more proactive manner to influence the strategies of governments in ways that accord higher priority to agricultural research and development.
- Better incentives and mechanisms are needed to identify viable indigenous technologies and commercialize them; this relates to the issue of farmers' rights, which can be promoted through farmer education and farmers' schools.



- The proposed increase in the extent of competitive grant funding is exacerbating the tensions among the various components of the national agricultural research systems: universities versus national agricultural research institutes; central versus zonal institutions; and strategic research versus applied/adaptive/participatory research. This encourages the research institutions to be competitors rather than partners.
- Universities need to become incubators for operational institutions such as agricultural enterprises and conservation organizations, and focal points for integration of national s&t activities with the changing global institutional ecology; they need to pursue academic excellence alongside an entrepreneurial orientation.



Annex B. Strategic actions for target audiences

Strategic actions for national governments

Science and technology options that can make a difference

- Adopt a market-led productivity improvement strategy.
- Adopt a production ecological approach with a primary focus on identified continental priority farming systems.
- Pursue a strategy of integrated sustainable intensification.
- Bridge the genetic divide .
- Recognize the potential of rainfed agriculture and accord it priority.
- Reduce land degradation and replenish soil fertility.
- Explore higher-scale integrated catchment strategies for natural resource management.
- Promote the conservation, sustainable and equitable use of biodiversity.
- Enhance use of mechanical power.
- Embrace information and communication technology at all levels.

Building impact-oriented research, knowledge and development institutions

- Design and invest in national agricultural science systems that involve farmers in education, research and extension.
- Encourage institutions and mechanisms to articulate science and technology strategies and policies.
- Cultivate African centres of agricultural research excellence.
- Increase support for agricultural research and development learning institutions.

Creating and retaining a new generation of agricultural scientists

- Focus on current and future generations of scientists in Africa.
- Broaden and deepen political support for agricultural science.
- Reform university curricula.
- Mobilize increased and sustainable funding for higher education in science and technology, minimizing dependence on external donor support.
- Strengthen science education at primary and secondary school levels.



Markets and policies to make the poor income and food secure

- Increase investments in rural infrastructure.
- Strengthen capacity to expand market opportunities.
- Institute effective intellectual property rights regimes to encourage the private sector and facilitate public-private partnerships.
- Reduce barriers to increased African trade with OECD countries.
- Improve data generation and analysis related to agriculture, food and nutrition security, and vulnerability.

Engaging science and technology for the benefit of African agriculture in the near term

- Implement a series of innovative participatory science and technology pilot programs focusing on four priority continental farming systems: maize mixed, cereal/root crop mixed, irrigated, and tree crop based.

Strategic actions for national agricultural research systems and university managers

Science and technology options that can make a difference

- Adopt a market-led productivity improvement strategy.
- Adopt a production ecological approach with a primary focus on identified continental priority farming systems.
- Pursue a strategy of integrated sustainable intensification.
- Bridge the genetic divide.
- Recognize the potential of rainfed agriculture and accord it priority.
- Reduce land degradation and replenish soil fertility.
- Explore higher-scale integrated catchment strategies for natural resource management.
- Promote the conservation, sustainable and equitable use of biodiversity.
- Enhance use of mechanical power.
- Embrace information and communication technology at all levels.
- Improve the coping strategies of farmers in response to environmental variability and climate change.

Building impact-oriented research, knowledge and development institutions

- Design and invest in national agricultural science systems that involve farmers in education, research and extension.



- Encourage institutions and mechanisms to articulate science and technology strategies and policies.

Creating and retaining a new generation of agricultural scientists

- Focus on current and future generations of scientists in Africa.
- Broaden and deepen political support for agricultural science.
- Reform university curricula.
- Mobilize increased and sustainable funding for higher education in science and technology, minimizing dependence on external donor support.
- Strengthen science education at primary and secondary school levels.

Engaging science and technology for the benefit of African agriculture in the near term

- Implement a series of innovative participatory science and technology pilot programs focusing on four priority continental farming systems: maize mixed, cereal/root crop mixed, irrigated, and tree crop based.

Strategic actions for the private sector

Science and technology options that can make a difference

- Adopt a market-led productivity improvement strategy.
- Bridge the genetic divide.
- Recognize the potential of rainfed agriculture and accord it priority.
- Enhance use of mechanical power.
- Embrace information and communication technology at all levels.

Building impact-oriented research, knowledge and development institutions

- Design and invest in national agricultural science systems that involve farmers in education, research and extension.
- Encourage institutions and mechanisms to articulate science and technology strategies and policies.
- Cultivate African centres of agricultural research excellence.
- Increase support for agricultural research and development learning institutions.



Creating and retaining a new generation of agricultural scientists

- Broaden and deepen political support for agricultural science.

Engaging science and technology for the benefit of African agriculture in the near term

- Implement a series of innovative participatory science and technology pilot programs focusing on four priority continental farming systems: maize mixed, cereal/root crop mixed, irrigated, and tree crop based.

Strategic actions for African subregional organizations

Science and technology options that can make a difference

- Adopt a market-led productivity improvement strategy.
- Adopt a production ecological approach with a primary focus on identified continental priority farming systems.
- Pursue a strategy of integrated sustainable intensification.
- Bridge the genetic divide.
- Recognize the potential of rainfed agriculture and accord it priority.
- Reduce land degradation and replenish soil fertility.
- Explore higher-scale integrated catchment strategies for natural resource management.
- Promote the conservation, sustainable and equitable use of biodiversity.
- Embrace information and communication technology at all levels.

Building impact-oriented research, knowledge and development institutions

- Encourage institutions and mechanisms to articulate science and technology strategies and policies.

Creating and retaining a new generation of agricultural scientists

- Broaden and deepen political support for agricultural science.

Engaging science and technology for the benefit of African agriculture in the near term

- Implement a series of innovative participatory science and technology pilot programs focusing on four priority continental farming systems: maize mixed, cereal/root crop mixed, irrigated, and tree crop based.



Strategic actions for the Forum for Agricultural Research in Africa (FARA)

Science and technology options that can make a difference

- Adopt a market-led productivity improvement strategy.
- Adopt a production ecological approach with a primary focus on identified continental priority farming systems.
- Pursue a strategy of integrated sustainable intensification.
- Bridge the genetic divide.
- Recognize the potential of rainfed agriculture and accord it priority.
- Reduce land degradation and replenish soil fertility.
- Promote the conservation, sustainable and equitable use of biodiversity.
- Embrace information and communication technology at all levels.

Building impact-oriented research, knowledge and development institutions

- Encourage institutions and mechanisms to articulate science and technology strategies and policies.

Creating and retaining a new generation of agricultural scientists

- Broaden and deepen political support for agricultural science.

Engaging science and technology for the benefit of African agriculture in the near term

- Implement a series of innovative participatory science and technology pilot programs focusing on four priority continental farming systems: maize mixed, cereal/root crop mixed, irrigated, and tree crop based.

Strategic actions for the New Partnership for Africa's Development (NEPAD)

Science and technology options that can make a difference

- Adopt a market-led productivity improvement strategy.
- Adopt a production ecological approach with a primary focus on identified continental priority farming systems.
- Pursue a strategy of integrated sustainable intensification.
- Bridge the genetic divide.
- Recognize the potential of rainfed agriculture and accord it priority.



- Reduce land degradation and replenish soil fertility.
- Explore higher-scale integrated catchment strategies for natural resource management.
- Promote the conservation, sustainable and equitable use of biodiversity.
- Enhance use of mechanical power.
- Embrace information and communication technology at all levels.

Building impact-oriented research, knowledge and development institutions

- Design and invest in national agricultural science systems that involve farmers in education, research and extension.
- Encourage institutions and mechanisms to articulate science and technology strategies and policies.
- Cultivate African centres of agricultural research excellence.

Creating and retaining a new generation of agricultural scientists

- Broaden and deepen political support for agricultural science.

Markets and policies to make the poor income and food secure

- Increase investments in rural infrastructure.
- Strengthen capacity to expand market opportunities.
- Institute effective intellectual property rights regimes to encourage the private sector and facilitate public-private partnerships.

Engaging science and technology for the benefit of African agriculture in the near term

- Implement a series of innovative participatory science and technology pilot programs focusing on four priority continental farming systems: maize mixed, cereal/root crop mixed, irrigated, and tree crop based.

Strategic actions for international agencies

Science and technology options that can make a difference

- Adopt a market-led productivity improvement strategy.
- Adopt a production ecological approach with a primary focus on identified continental priority farming systems.
- Pursue a strategy of integrated sustainable intensification.
- Recognize the potential of rainfed agriculture and accord it priority.



- Reduce land degradation and replenish soil fertility.
- Explore higher-scale integrated catchment strategies for natural resource management.
- Promote the conservation, sustainable and equitable use of biodiversity.
- Embrace information and communication technology at all levels.
- Improve the coping strategies of farmers in response to environmental variability and climate change.

Building impact-oriented research, knowledge and development institutions

- Increase support for agricultural research and development learning institutions.
- Strengthen international agricultural research centres.

Creating and retaining a new generation of agricultural scientists

- Mobilize increased and sustainable funding for higher education science and technology, minimizing dependence on external donor support.

Markets and policies to make the poor income and food secure

- Increase investments in rural infrastructure.
- Strengthen capacity to expand market opportunities.
- Institute effective intellectual property rights regimes to encourage the private sector and facilitate public-private partnerships.
- Improve data generation and analysis related to agriculture, food and nutrition security, and vulnerability.

Engaging science and technology for the benefit of African agriculture in the near term

- Implement a series of innovative participatory science and technology pilot programs focusing on four priority continental farming systems: maize mixed, cereal/root crop mixed, irrigated, and tree crop based.

Strategic actions for OECD and donor countries

Science and technology options that can make a difference

- Adopt a market-led productivity improvement strategy.
- Adopt a production ecological approach with a primary focus on identified continental priority farming systems.



- Pursue a strategy of integrated sustainable intensification.
- Bridge the genetic divide.
- Recognize the potential of rainfed agriculture and accord it priority.
- Reduce land degradation and replenish soil fertility.
- Explore higher-scale integrated catchment strategies for natural resource management.
- Promote the conservation, sustainable and equitable use of biodiversity.
- Embrace information and communication technology at all levels.

Building impact-oriented research, knowledge and development institutions

- Increase support for agricultural research and development learning institutions.
- Strengthen international agricultural research centres.

Creating and retaining a new generation of agricultural scientists

- Mobilize increased and sustainable funding for higher education in science and technology, minimizing dependence on external donor support.

Markets and policies to make the poor income and food secure

- Increase investments in rural infrastructure.
- Strengthen capacity to expand market opportunities.
- Institute effective intellectual property rights regimes to encourage the private sector and facilitate public-private partnerships.
- Reduce barriers to increased African trade with OECD countries.

Engaging science and technology for the benefit of African agriculture in the near term

- Implement a series of innovative participatory science and technology pilot programs focusing on four priority continental farming systems: maize mixed, cereal/root crop mixed, irrigated, and tree crop based.



Strategic actions for the Consultative Group on International Agricultural Research (CGIAR), international agricultural research centres, and advanced research institutes

Science and technology options that can make a difference

- Adopt a market-led productivity improvement strategy.
- Adopt a production ecological approach with a primary focus on identified continental priority farming systems.
- Pursue a strategy of integrated sustainable intensification.
- Bridge the genetic divide.
- Recognize the potential of rainfed agriculture and accord it priority.
- Reduce land degradation and replenish soil fertility.
- Explore higher-scale integrated catchment strategies for natural resource management.
- Promote the conservation, sustainable and equitable use of biodiversity.
- Embrace information and communication technology at all levels.
- Improve the coping strategies of farmers in response to environmental variability and climate change.

Building impact-oriented research, knowledge and development institutions

- Encourage institutions and mechanisms to articulate science and technology strategies and policies.
- Strengthen international agricultural research centres.

Creating and retaining a new generation of agricultural scientists

- Focus on current and future generations of scientists in Africa.

Engaging science and technology for the benefit of African agriculture in the near term

- Implement a series of innovative participatory science and technology pilot programs focusing on four priority continental farming systems: maize mixed, cereal/root crop mixed, irrigated, and tree crop based.



Annex C. Study panel biographies

Co-chairs

Speciosa Wandira KAZIBWE is former Vice-President of the Republic of Uganda and a former Minister of Agriculture, Animal Industry and Fisheries. She is currently enrolled in a Ph.D. program at Harvard University. She received a medical degree from Makerere University in Kampala. She has been very active in programs relating to youth and women. She was a Councilor in the Kampala City Council, a Representative in the Parliament and a member of the assembly that drafted Uganda's new Constitution. She has also been active in the World Forestry Commission, the International Food Policy Research Institute, the World Water Commission, the High Level Panel of Advisors to the Secretary-General of the UN on the Development of Africa and the African Women Committee on Peace and Development. She was awarded the FAO CERES Medal in 1998 for her contributions to food security and poverty eradication.

Rudy RABBINGE is Dean of the Wageningen Graduate School in The Netherlands and university professor for sustainable development and systems innovation. A biologist by training, he worked for the past 30 years in various functions on the ecologization of agriculture. As Professor of theoretical production ecology (1978-1998), he initiated programs in the application of basic knowledge to innovative processes for primary production and systems approaches in agricultural research. He has led various missions and agricultural programs in developing countries, served as editor of several journals, published more than 100 scientific publications, five textbooks and more than

200 other publications. He served on the Board of six centers in international agricultural research and was Chairman of the Board of IRRI (1995-2000). He was member of the Netherlands Prime Minister's Scientific Council for Government Policy (1988-1998) and senior advisor to the Minister of Agriculture, Fisheries and Nature (1992-1999). He is at present a member of the Senate of the Netherlands Parliament, Vice-chairman of the Royal Institute of the Tropics and member of the Board of various international agri-business firms.

M.S. SWAMINATHAN has worked for the past 45 years with scientists and policy makers on a wide range of problems in basic and applied plant genetics, as well as in agricultural research and development. As Secretary of the Ministry of Agriculture and Co-operation, he developed a strong food security system in India. As one of the leaders of the Green Revolution in India, he now recognizes the need for an 'Evergreen Revolution' to extend the benefits of development to the most marginalized. His work in crop genetics and sustainable agricultural development in India and the Third World earned him the first World Food Prize in 1987, the Tyler and Honda Prizes in 1991 and the UNEP Sasakawa Award in 1994. He served as Director-General of the Indian Council of Agricultural Research (1972-1978) and of the International Rice Research Institute (1982-1988). He served as independent Chairman of the FAO Council (1981-1985) and as the President of International Union for the Conservation of Nature and Natural Resources (1984-1990). He was the President of National Academy of Agricultural Sciences of India and is member of various

academies including the Royal Society of London, the US National Academy of Sciences, the Russian Academy of Sciences and the Chinese Academy of Sciences.

Panel members

Mohamed BESRI became Doctor-engineer in Agronomy and Doctor in Plant Pathology at the University of Nancy, France. Additional training took place in the United States, Denmark, Holland, Spain, France, Belgium and India. At present he is Professor in plant pathology and integrated diseases management at the Hassan II Institute of Agronomy and Veterinary Medicine, Morocco, and Director/Dean of the graduate school. He is an expert in soil and airborne pathogens, integrated pest management of various crops (particularly vegetables and fruits), alternatives to methyl bromide, evaluation of research and teaching activities, evaluation of the impact of education on agricultural development, implementation and coordination of national and international research projects, pesticides use and distribution. He is consultant to FAO, USAID, UNDP, UNEP, the European Union and other governmental and non-governmental international organizations. He was visiting professor at many American, European and African universities, he was Vice-President and President of the Arab Society for Plant Protection and he is a member of various national and international associations. Has published some 100 papers in international and national journals and books.

Maria Manuela CHAVES is Professor at the Faculty of Agronomy (ISA) of the Technical University of Lisbon (UTL)



and leader of the Plant Molecular Ecophysiology Laboratory of the Instituto de Tecnologia Química e Biológica (ITQB), Oeiras. From 1992-2002 she was coordinator of the Research Center on Botany Applied to Agriculture of the UTL. Her background is in agronomy and her scientific interests in the past 30 years have been in plant ecophysiology, in particular studying plant/crop response and adaptation to stressful environments. She was national coordinator of several EU-funded research projects. This work includes improvement of forage crops for semi-arid areas (1993-1997); natural resource development and utilization in the Sahel (together with partners in India, Senegal and Ivory Coast from 1993-1997); and partial root drying, a sustainable irrigation system for efficient water use without reducing fruit yield (together with Morocco, Cyprus and Turkey from 2000-2003). Also, her work includes the future of the tropical forest carbon sink (with a EU/Brasil consortium from 2000-2002), network for ecophysiology in closing terrestrial carbon budget (2000-2003) and diagnosis and analysis of plant stress using thermal and other imaging techniques (2002-2006). She was the first Chair of the Portuguese Committee for the International Geosphere-Biosphere Programme (IGBP). She participated in conferences in Europe, South America, China and Africa. She is member of the editorial board of two major international journals in plant sciences.

Avílio Antonio FRANCO graduated in Agronomy at the Universidade Rural do Brasil, and earned a masters degree in microbiology at the University of New South Wales, Australia; a PhD in soil science at the University of California; and was a visiting Academic at the University of Queensland, Australia. He works with the Empresa Brasileira de Pesquisa Agropecuária (Embrapa) at the Centro Nacional de Pesquisa em

Agrobiologia (Embrapa Agrobiologia). His research of biological nitrogen fixation in Phaseolus bean, soybean and tropical legume trees has had great impact on the expansion of the two crops in Brazil and the development of a technology on land reclamation using nodulated and mycorrhizal legume trees that was awarded the 2001 von Martius prize. At present he is in the Agronomy Advisory Committee of the Brazilian National Research Council and the Rio de Janeiro State Agriculture Research Enterprise and Adviser of the Rio de Janeiro 'Carlos Chagas Filho' Foundation to support Science and Technology. He is member of the Brazilian National Academy of Science and the Third World Academy of Science.

Jikun HUANG is Professor and Chief Scientist at the Institute of Geographical Sciences and Natural Resources Research in China, as well as the Founder and Director of the Center for Chinese Agricultural Policy (CCAP) of the Chinese Academy of Sciences. His research and publications cover a wide range of issues on China's agricultural and rural economy, including work on agricultural R&D policy, resource and environmental economics, price and marketing, food consumption, poverty, and trade liberalization. He has led more than forty research projects funded both internationally and domestically. He also serves as professor in Nanjing Agricultural University, Zhejiang Universities, and Xingjiang Agricultural University in China. He has been a consultant to several international organizations (World Bank, FAO, OECD and others) and policy consultant to several ministries in China. He has received several awards and prizes from the Chinese Government. He has received the Outstanding Scientific Progress awards from the Ministry of Agriculture three times.

Ryuichi ISHII graduated from the Faculty of Agriculture, University of Tokyo,

in 1967 with a major in crop science. After several research positions with the University of Tokyo, he became Associate Professor at the Faculty of Agriculture, University of Tokyo, in 1979. In 1982 he became Associate Professor and in 1987 Professor in crop science at that Faculty. In 1998 he was visiting professor at the China Agriculture University. His present position is Professor of crop science at the College of Biore-source Science, Nihon University. He has been involved in several international research projects: Japan-USA on carbon metabolism in plants (1984), Japan-Brazil on photosynthesis of wheat cultivars under water stress conditions (1985), research project in Ghana on photosynthetic characteristics of *oryza glaberrima* (1988), with the International Rice Research Institute (IRRI) on physiological characterization of new plant type rice (1994), with the Royal Prikulthon Development Center, Thailand, on crop production under acidic soil conditions and with the West Africa Rice Development Association (WARDA) on agronomic characterization of interspecific hybrid rice progenies between *oryza sativa* and *oryza glaberrima*. He organized several international congresses and he is President of the Crop Science Society of Japan and member of Board of WARDA, Cote d'Ivoire.

Renald LAFOND is a Senior Program Specialist in information and communication technologies (ICT) for development at the International Development Research Centre (IDRC), Canada. He is the Team Leader of the Pan Network Program Initiative, a research program on ICTs and development and networking in developing countries. Recent emphasis of this program was on rural access to ICTs. He is a professional engineer and holds a Master degree in chemical engineering from Laval University, Canada (1968). He worked a few years in applied industrial research



and was later involved in the establishment of an information service for small industries in Quebec. He worked for more than six years with the United Nations Industrial Development Organisation (UNIDO) in Africa and Vienna before joining the Information Sciences Division of IDRC in Ottawa in 1985. At IDRC he was initially responsible for the development of an information program for small industries in the Science and Technology Information Program, covering Africa, Asia and Latin America. He was involved in various other information activities, in particular in the area of agricultural information, mainly in Africa. He has been involved in the development of the PAN Global Networking Initiative since 1994 in Asia and Latin America and he was associated to the development of a similar program for Africa.

Peter MATLON is Deputy Director for Food Security at the Rockefeller Foundation, New York. His responsibilities include supporting the Foundation's grant making in science and technology, market development, policies and capacity building in the field of agriculture. Earlier, he held positions as: Group Leader, Environmentally Sustainable Development Group of UNDP (2001); Chief, Global Programme for Food Security and Agriculture, Sustainable Energy and Environment Division of UNDP (1997-2000); Director of Research at the West Africa Rice Development Association (1988-1997); Principal Economist and West African Economics Program Leader at ICRISAT (1979-1988); and Assistant Professor, Department of Agricultural Economics, Michigan State University (1977-1979). He obtained a PhD in agricultural economics at Cornell and a MPA in development economics at Princeton. He is member of the Board of international journals, has been a consultant to the World Bank and other national and international organizations and serves on the Board of

numerous scientific cooperation arrangements in the field of agriculture. He has published extensively.

Ahmadou Lamine NDIAYE, graduated at the Veterinary school of Lyon and specialized in animal production at the Institut National Agronomique de Paris and in 1974 became Agrégé des Ecoles Nationales Vétérinaires Françaises in animal production and nutrition. He is a former Minister and Special advisor to the Head of State, Senegal. Previously he was Head of the Veterinary School of Senegal, Dakar, 1976-1986, and Rector of the University of Saint Louis, Senegal, 1990-1999. He was Chairman of the organizing committee for the Biennial Conference on science and technology in Senegal, AFRISTECH, and Chairman of the AFRISTECH Foundation. He is member of the editorial panel for several publications, such as the Bulletin of Health and Animal production in Africa. He was awarded the Bronze Medal of the Cattle Breeding and Veterinary Institute for Tropical Countries and the Silver Medal of the France Veterinary Academy. He is a member of the African Academy of Sciences and Vice-President of the Academy of Sciences and Technology of Senegal and Chairman of the Agricultural Sciences section of that Academy. He is member of the United Nations University Council and the Executive Board of the Association of African Universities and involved with capacity development in Africa, as well as university cooperation. His research areas focus on valorization of harvest residues and agro-industrial by-products for animal feed. Numerous publications in professional journals

Bongiwe NJOBE is Director General of the South African Department of Agriculture. Prior to this post she was Professor in the agricultural faculty of Pretoria University. She has worked on all aspects of agriculture, from academia and production to government. Born in

South Africa, she spent most of her childhood in Zambia. In 1979 she studied in Bulgaria, where she attained a master of agriculture degree. During college summer holidays she did practical training, working on an African National Congress farm in Tanzania. Back in Zambia she worked for a small fruit and vegetable export company, then moved to Canada, where she helped with a subsistence self-training program and worked with non-governmental organizations and various agricultural industries. She then began lecturing at the School of Agriculture and Rural Development at the University of Pretoria. In 1995 she participated in the development of the ANC's agricultural policy, serving on a committee which looked at broadening access to agriculture for owners, entrepreneurs, scientists and service providers.

Emmanuel Uche ODIGBOH is Professor of Agricultural Engineering at the University of Nigeria since 1978. He obtained a BSc at Technion, Israel (1966) and a MSc and PhD at Pennsylvania State University, USA (1972 and 1974). In 1981 he established Agromech Consultancy Services Inc. within the University's Department of Agricultural Engineering. He has consulted extensively for private and public organizations on agricultural mechanization, agribusiness development, integrated rural development, soil and water resources management and the development of post-harvest technology systems. He served for two terms as Dean of Engineering (1982-1984 and 1995-1998) and he has been Acting Deputy Vice Chancellor (1989). Since 1997, he has been Chairman of the University's Consultancy Management Board. He was National President of the Nigerian Society of Agricultural Engineers (1980-1982) and he served on the Governing Council of the National Center for Agricultural Mechanization (1994) and the management board of Anambra State Agricul-



tural Development Corporation. He has published over one hundred articles and books in national and international journals and he has designed and developed over fifteen unique agricultural production and processing machines.

Gideon ORON is Professor and research leader at the Environment Water Resources Center, The Institute for Desert Research, Ben-Gurion University of the Negev, Kiryat Sde-Boker, Israel, as well as the Department of Industrial Engineering and Management, Ben-Gurion University of the Negev. He obtained a M.Sc. (1969) and a PhD. (1975) at Technion, Israel Institute of Technology, Haifa, Israel. Currently he is the chair of the Membrane Special Group of IWA. His main research interests are application of operations research; water resources; environmental systems; management modeling; wastewater treatment and reuse; membrane technology; aquaculture for wastewater reclamation; optimal marginal water use primarily in arid regions and irrigation. He conducted research projects on: wastewater treatment by anaerobic methods; wastewater treatment by aquaculture methods and stabilization ponds systems; effluent reuse for irrigation; saline water use for irrigation; remote sensing methods for quality control of large water and waste water bodies; use of membrane technology for effluent quality control; biopolymers use for effluent polishing; sludge management; and water resources management in arid zones. He has cooperative ongoing research projects with several European countries, USA, several countries in the Middle East and North Africa. In the past he had also close research ties with countries in the Far East.

Per PINSTRUP-ANDERSEN, a native of Denmark, joined the International Food Policy Research Institute (IFPRI) as its Director General in 1992. Prior to this,

he was director of the Cornell Food and Nutrition Policy Program, professor of food economics at Cornell University and a member of the Technical Advisory Committee to the CGIAR. Before taking up his teaching and research positions at Cornell, he served as a research fellow and director of the Food Consumption and Nutrition Policy Program at IFPRI, as an agricultural economist at the International Center for Tropical Agriculture (CIAT) in Colombia, as director of the Agro-Economic Division at the International Fertilizer Development Center (IFDC) in the United States and as an associate professor of the Danish Veterinary and Agricultural University in Copenhagen. He is a Fellow of the American Agricultural Economics Association and the American Association for the Advancement of Science (AAAS). He is the recipient of the 2001 World Food Prize for his contribution to the improvement of agricultural research, food policy and the lives of the poor.

Elly N. SABIITI is Dean of the Faculty of Agriculture and Forestry, Makerere University, Uganda. He obtained a BSc and a MSc in agricultural science from Makerere University (1973-1979) and a PhD from the University of New Brunswick, Canada (1983-1985). In 1985 he was appointed Lecturer in the Department of Crop Science, Makerere University, and in 1995 Professor of Crop Science. His research focuses on the use of forage legumes in crop and livestock farming systems and on range resource management. He holds membership in many professional organizations and he is a founding member of the Association of Uganda Professional Agriculturalists. He published about 30 articles in refereed international journals and he has more than 150 other publications on his name. He is a member of the Steering Committee of the African Feed Resources Network and he serves on several committees of the National Agriculture Research Organization. In

2002 the Ugandan Minister of Agriculture, Animal Industry and Fisheries appointed him Director of the Board of the National Agricultural Advisory Services. He also is member of the National Task Force to prepare a National Agricultural Education strategy. He was awarded a Fulbright Fellowship for Senior African Scholars (1994), he is a member of the Uganda National Academy of Sciences and he is a Fellow of the Third World Academy of Science.

José SARUKHAN is Professor of Ecology at the Autonomous National University of Mexico (UNAM) in Mexico City. He was educated at UNAM in Biology, 1958-1961. He obtained an Agricultural Botany Master at the Postgraduate College, Chapingo, Mexico, 1963-1965, and a PhD in ecology at University College of North Wales, 1968-1972. Since 1978 he has been on the research staff of the Institute of Ecology, Mexico. From 1992 onwards he has been National Coordinator of the Mexican National Commission on Biodiversity (CONABIO). Other positions include: Vice-Chancellor for Science, UNAM, 1987-1988, Director Institute of Biology, UNAM, 1979-1987, Senior Research Staff, Institute of Biology, UNAM, 1972-1978, Rector of UNAM, 1989-1992 and 1992-1996 and Tinker Professor, Stanford University, 1997-1998. His research focuses on plant population ecology, systems ecology of tropical ecosystems and biodiversity science. He is the recipient of many awards and prizes. He received four honorary doctorates and is a foreign member of the National Academy of Sciences, USA.

Jennifer THOMSON is Professor in the Department of Molecular and Cell Biology at the University of Cape Town, past Head of the Department of Microbiology (1988-2000) and Deputy Dean Faculty of Science (1996-98). She was Associate Professor at the University of the Witwatersrand, Visiting Scientist at



the Massachusetts Institute of Technology, USA, Director of the Laboratory for Molecular and Cell Biology of the Council for Scientific and Industrial Research, South Africa, and Research and Teaching Fellow at Harvard University. Her research has focused on the development of maize resistant to the African endemic maize streak virus through molecular biology techniques. She has also been involved in development of maize and other crops tolerant to drought and other abiotic stresses. She has written many scientific papers on microbiological subjects and has published a book, *Genes for Africa: Genetically Modified Crops in the Developing World*, aimed at explaining to decision makers and the general public the issues involved in utilizing GMO techniques in a developing country context. She has had wide interaction with workers in many African countries, including running workshops and training programs in Nigeria, Zimbabwe and Kenya, etc. She has been recipient of several awards and fellowships and she was Vice-President of the Academy of Science of South Africa. She serves as an adviser to the WHO and other organizations.

Study director

Jim RYAN is an Australian agricultural economist with a PhD in economics from North Carolina State University in 1972, a Master of Science in Agriculture in 1969 and a Bachelor of Science in Agriculture in 1962, both from the University of Sydney. He was awarded membership of the Honor Societies of Phi Kappa Phi and Gamma Sigma Delta in the U.S. and is a Fellow of the Australian Institute of Agricultural Science and Technology. He has specialized in studies of the economics of agricultural research and technological change in developing countries, including implications for employment and human nutrition. He has more than 120 publications. He was Leader of the Economics Program at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad India (1974-83), Deputy Director and Chief Scientist of the Australian Center for International Agricultural Research in Canberra Australia (1983-91), and Director General of ICRISAT (1991-97). Since May 2000 he has been a Visiting Fellow in the Research School of Pacific and Asian Studies of the Australian National University in Canberra. He has been a member of the Boards of the Asian Vegetable Research and Development Cen-

ter (AVRDC) in Taiwan and the International Maize and Wheat Improvement Center (CIMMYT) in Mexico, and served as a member of the Technical Advisory Committee of the Consultative Group on International Agricultural Research. He has led a review of the Australian agricultural aid program for AusAID, chaired the Sixth External Program and Management Review of AVRDC and was a member of the first External Program and Management Review Panel of the International Service for National Agricultural Research. Current interests and recent assignments include the assessment of the economic impacts of agricultural and policy research, future strategies and priorities for international livestock research, and the prospective challenges and opportunities for agricultural R & D in the semi-arid tropics.



Annex D. Glossary

Commercial crops or farms: Those where a major portion of production is sold in the market. They can be food, beverage or non-food crops and involve smallholders as well as large farms.

Inter-cropping: Where in the same field more than one crop species is grown at the same time either by mixing the seeds and broadcasting them at sowing in random associations, or planting rows of the individual species in a specific sequence or spatial arrangement.

Malnutrition: When the intake of nutrients falls below some recommended daily allowance or a person's anthropometry is below recognized norms. It is used interchangeably with the term undernutrition in this report.

Mixed cropping: Where more than two crop species are grown on a farm, often in association in the same field but sometimes in separate fields.

Mono-cropping: Where the same crop species is grown in the same field continuously year after year.

Poverty Reduction Strategy Paper: A document describing a country's macroeconomic, structural and social policies and programs to promote growth and reduce poverty, as well as associated external financing needs. They are prepared by governments through a participatory process involving civil society and development partners, including the World Bank and the International Monetary Fund.

Smallholders: Owners or operators of small farms with primary reliance on family labour who are at or below the poverty line. They can be subsistence or commercial farms, or something in between.

Sole cropping: Where one crop species is grown in a field or farm on its own in a given year rather than in a mixture.



Subsistence crops or farms: Those where the bulk of production is retained for home consumption rather than sold on the market. Usually restricted to food crops.

Undernutrition: When the intake of nutrients falls below some recommended daily allowance or a person's anthropometry is below recognized norms. It is used interchangeably with the term malnutrition in this report.



Annex E. Abbreviations and acronyms

AARINENA	Association of Agricultural Research Institutes in the Near East and North Africa
AATF	African Agricultural Technology Foundation
ACARE	African centre of agricultural research excellence
ACBF	African Capacity Building Foundation
AERC	African Economic Research Consortium
AgGDP	Agricultural gross domestic product
AGORA	Access to Global On-line Research in Agriculture
AKIS	Agricultural knowledge information system
ARC	Agricultural Research Corporation (Sudan)
AREU	Agricultural Research and Extension Unit (Mauritius)
ARI	Advanced research institute
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ASTI	Agricultural Science and Technology Indicators (project)
AVU	African Virtual University
BIFAD	Board of International Food and Agricultural Development
CAADP	Comprehensive African Agricultural Development Programme (of NEPAD)
CBD	Convention on Biological Diversity
CBO	Community-based organisation
CGIAR	Consultative Group on International Agricultural Research
CIESIN	Centre for International Earth Science Information Network
CIHEAM	Centre International de Hautes Etudes Agronomiques Méditerranéennes
CIMMYT	International Maize and Wheat Improvement Center
CIRAD	Centre de Coopération Internationale en Recherche Agronomique pour le Développement
CNRA	Centre National de Recherche Agronomique (Côte d'Ivoire)
CORAF	Le Conseil Ouest et Centre Africain pour la Recherche et le Développement Agricoles (WECARD)
DARHRD	Directorate of Agricultural Research and Human Resources Development (Eritrea)
DFID	Department for International Development (U.K.)



DRD	Department of Research and Development (Tanzania)
EARO	Ethiopian Agricultural Research Organization
EU	European Union
FAO	Food and Agriculture Organization (United Nations)
FARA	Forum for Agricultural Research in Africa
FOFIFA	National Centre for Applied Research on Rural Development (Madagascar)
FTE	Full time equivalent
GDP	Gross domestic product
GFAR	Global Forum for Agricultural Research
GIS	Geographic Information System
GMO	Genetically modified organism
GNEST	Global Network of Ethiopians for Science & Technology
HIV/AIDS	Human Immunodeficiency Virus/Acquired Immune Deficiency Syndrome
IAC	InterAcademy Council
IAP	InterAcademy Panel on International Issues
IARC	International agricultural research centre
ICARDA	International Centre for Agricultural Research in Dry Areas
ICIPE	International Centre for Insect Physiology and Ecology
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ICT	Information and communication technology
IFDC	International Center for Soil Fertility and Agricultural Development
IITA	International Institute for Tropical Agriculture
ILRI	International Livestock Research Institute
IPGRI	International Plant Genetics Resources Institute
IPM	Integrated pest management
IPR	Intellectual property rights
IRD	Research Institute for Development (previously ORSTOM) (France)
ISABU	Institut des Sciences Agronomiques du Burundi
ISNAR	International Service for National Agricultural Research
ISRA	Agricultural Research Institute of Senegal
ITC	International Trade Centre (technical cooperation agency of UNCTAD and WTO)
KARI	Kenyan Agricultural Research Institute
MAPP	Multi-Country Agricultural Productivity Program (World Bank)



MSIRI	Mauritius Sugar Research Institute
NAADS	National Agricultural Advisory and Development Service (Uganda)
NAREES	National agricultural research, education and extension system
NARI	National agricultural research institute
NARO	National Agricultural Research Organization (Uganda)
NARS	National agricultural research system
NEPAD	New Partnerships for Africa's Development
NERICA	New Rice for Africa
NGO	Nongovernmental organization
NUTMON	Nutrient monitoring at farm level
OECD	Organization for Economic Cooperation and Development
PRSPs	Poverty Reduction Strategy Papers
QPM	Quality Protein Maize
R&D	Research and development
S&T	Science and technology
SACCAR	Southern African Centre for Cooperation in Agricultural Research
SADC	Southern African Development Community
SFI	Sustainable Financial Initiative (World Bank, USAID and SPAAR)
SPAAR	Special Program for African Agricultural Research
SRO	Subregional organization
TEEAL	The Essential Electronic Agricultural Library (Cornell University)
TOKEN	Transfer of Knowledge through Expatriate Nationals
TRIPS	Trade-related aspects of intellectual property rights
TRIT	Tea Research Institute of Tanzania
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Program
UNEP	United National Environment Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPOV	l'Union Internationale pour la Protection des Obtentions Végétales (International Union for the Protection of New Varieties of Plants)
USAID	United States Agency for International Development



WARDA	West African Rice Development Association
WECARD	West and Central African Council for Agricultural Research and Development = CORAF
WHO	World Health Organization (United Nations)
WIPO	World Intellectual Property Organization
WTO	World Trade Organization



Annex F. List of boxes, figures, and tables

Boxes

- Box 1.1 Letter from the Secretary-General of the United Nations 2
- Box 3.1 Importance of livestock in African farming systems 26
- Box 3.2 Farming system characteristics 28
- Box 3.3 Systematically disentangling factors that affect growth and yield 38
- Box 3.4 Yield gap analysis 41
- Box 3.5 Best technical means 42
- Box 4.1 Production potential of Sub-Sahara Africa 73
- Box 4.2 New Rice for Africa (NERICA) 75
- Box 4.3 Grazing land requirements and manure for arable farming 80
- Box 4.4 Lethal animal diseases constrain production 81
- Box 4.5 Putting Africa's rich biodiversity to work 83
- Box 4.6 Agroforestry 84
- Box 4.7 The challenge of integrated water resource management 85
- Box 4.8 Legumes and plant-bacteria associations 86
- Box 4.9 Multidisciplinary fight against Striga 89
- Box 4.10 African Agriculture Technology Foundation 90
- Box 4.11 Some promising biotechnologies 91
- Box 4.12 Application and adoption of biotechnologies 91
- Box 4.13 Enhancing the benefits of intercropping maize and sesame 99
- Box 4.14 The evolution of crop-livestock systems in West Africa 100
- Box 4.15 Nutrient monitoring at farm level (NUTMON) 101
- Box 5.1 The evolution of African universities 118
- Box 5.2 Institutional innovations 139
- Box 5.3 New thoughts on agricultural extension 140
- Box 5.4 Roles of information and communications technology in the participatory knowledge quadrangle 143
- Box 5.5 North African National Agricultural Research Systems 157
- Box 7.1 The benefits of globalization and trade liberalization to Africa 193
- Box 7.2 Increased investment in infrastructure lifts productivity and benefits the poor 197



Figures

Figure 2.1	The nutritional challenge over the life cycle	11
Figure 3.1	African farming systems	28
Figure 3.2	Land productivity trends of the major commodities in African farming systems	36
Figure 3.3	The relative impact of radiation, water, nitrogen and phosphorus on growth of annual grasses in the Sahel	38
Figure 3.4	Principles of production ecology and factors affecting growth and yield and food availability	40
Figure 3.5	Yields analyzed according to production ecological principles and under actual field conditions	41
Figure 3.6	Schematic relation between nutrient recovery and agro-ecological conditions	42
Figure 3.7	Trends in the use of fertilizers in farming systems in Africa	48
Figure 3.8	Characteristics of the priority systems	55
Figure 3.9A	Underweight densities and proposed hunger hotspots	56
Figure 3.9B	Hunger hotspots in major farming systems	56
Figure 3.9C	Population density 1995	57
Figure 3.9D	Soil constraints combined	57
Figure 3.9E	Soil texture constraints	57
Figure 3.9F	Soil fertility constraints	57
Figure 4.1	Changes in the total agricultural (crop plus livestock) production index number (PIN), agricultural land use (arable land, permanent crops and permanent pasture) and labour input in the four priority systems	70
Figure 4.2	Changes in the crop production index number (PIN), crop land use (arable land and permanent crops) and fertilizer use in the four priority systems	71
Figure 4.3	Changes in the livestock production index number (PIN) and non-crop land use (permanent pasture) in the four priority systems	72
Figure 4.4	Calculated potential (a) and water-limited (b) yields (tonnes per hectare)	73
Figure 4.5	Actual average cereal yields at the national level	74
Figure 5.1A-B	Distribution of African agricultural research capacity by FTE researchers and R&D expenditures	117



Figure 5.2	Agricultural priorities as reflected by the poverty reduction strategies of 24 African countries	127
Figure 5.3 A-B	Total African agricultural R&D spending and staff by institutional category, 2000-2001	148
Figure 5.4	Trends in public spending by institutional category in selected African countries, 1971-2000	149
Figure 5.5 A-D	Trends in public expenditures, researchers, and expenditures per researcher in selected African countries, 1971-2000	150
Figure 5.6	Share of female researchers in selected African countries, 2000	152
Figure 5.7	Africa's agricultural research intensity compared regionally and globally, 1995	152
Figure 5.8	Funding sources for national agricultural research in selected African countries, 2000	155
Figure 5.9	Cost-category shares in expenditures for the main agricultural research agencies in selected African countries, 2000	155
Figure 5.10 A-B	Commodity focus of agricultural research expenditures in selected African countries, 2000	156
Figure 5.11	Modern variety diffusion by decade and region (percent area planted to modern varieties)	160

Tables

Table 2.1	Factors involved in attaining food security	12
Table 2.2	The extent of child malnutrition in Sub-Saharan Africa farming systems	14
Table 3.1	Farming systems of Sub-Saharan Africa, North Africa and the Middle East	25
Table 3.2	Major animal production systems in African agro-ecological zones	27
Table 3.3	Irrigated land in farming systems in Africa in 2000	49
Table 3.4	Proportions of rainfed areas and production totals in 1995 and projected to 2021-25 in Africa	49
Table 3.5	Indicators for priority assessment in ten major African farming systems	54
Table 3.6	Major characteristics of suggested priority farming systems	60



Table 3.7	Productivity trends for various commodities in the suggested priority farming systems	61
Table 4.1	Gaps in rice yields in various rice ecologies and most relevant constraints to current production	77
Table 4.2	Yield increase in maize due to the adoption of a technology package, comprising improved varieties, fertilizers and pesticides	78
Table 4.3	Constraints to and strategies for adoption of cereal (sorghum and millet) production in the West African semi-arid tropics	79
Table 4.4	The top ten livestock diseases/pathogens according to their impact on the poor	81
Table 5.1	Classification of African countries by the size of their national agricultural research system	116
Table 5.2	Composition of expenditures and researchers in agricultural research and development in selected African countries, 2000	147
Table 5.3	Agricultural R&D intensity ratios in selected African countries for 1981, 1991, and 2000	153
Table 5.4	Rates of return to selected agricultural research projects or programs by geographical region	158
Table 6.1	Comparative cost of graduate degrees in agriculture in various universities	175
Table 7.1	Net gains in economic welfare from global trade liberalization towards 2025	193
Table 7.2	Returns to government investments in rural Uganda	197
Table 8.1	Target audiences and time frames for impact of strategic recommendations	232-233