Realizing the promise and potential of African agriculture

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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

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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:

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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 Counseil 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 Nwalozie, 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 InterAcademy 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-ecosystems 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 malnutrition 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 t 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-

rangle' 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 communications 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 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 co-operatives 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 agroecosystems 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.

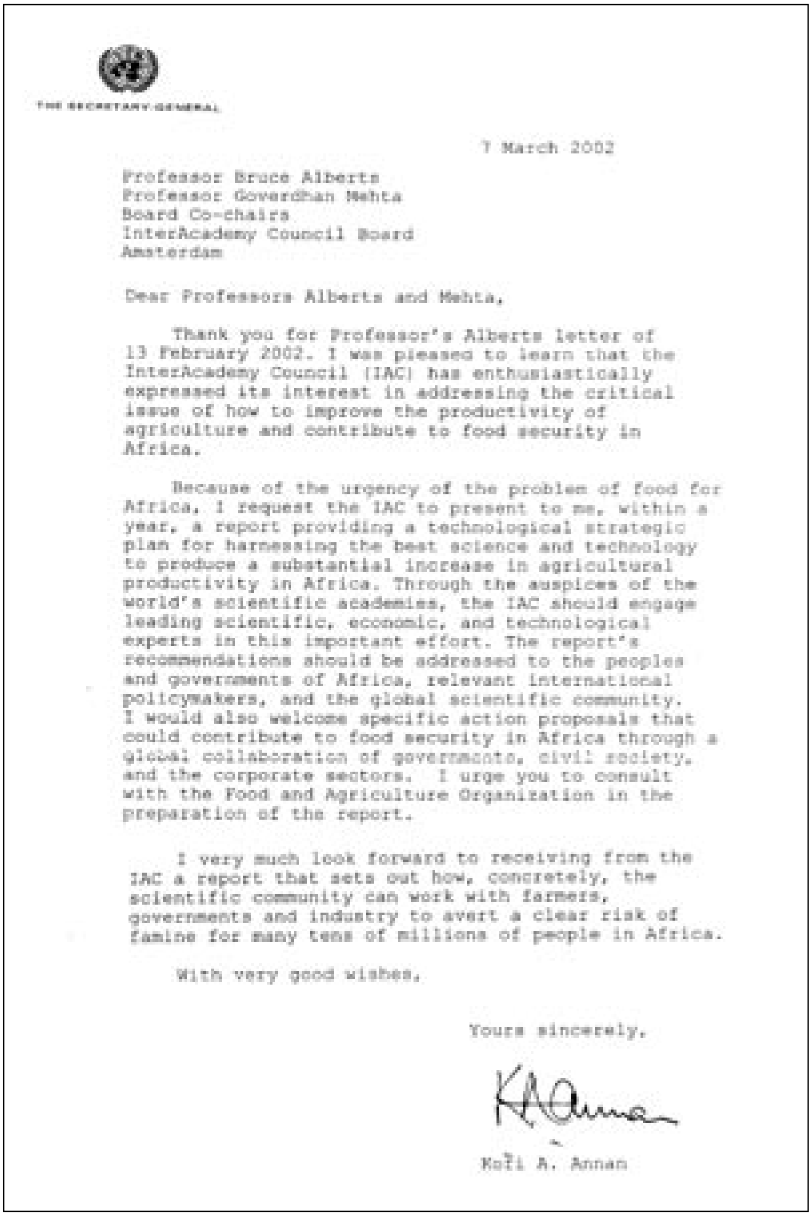
1. Introduction

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 SECRETARY-GENERAL

7 March 2002

Professor Bruce Alberts
Professor Goverdhan Mehta
Board Co-chairs
InterAcademy Council Board
Amsterdam

Dear Professors Alberts and Mehta,

Thank you for Professor's Alberts letter of 13 February 2002. I was pleased to learn that the InterAcademy Council (IAC) has enthusiastically expressed its interest in addressing the critical issue of how to improve the productivity of agriculture and contribute to food security in Africa.

Because of the urgency of the problem of food for Africa, I request the IAC to present to me, within a year, a report providing a technological strategic plan for harnessing the best science and technology to produce a substantial increase in agricultural productivity in Africa. Through the auspices of the world's scientific academies, the IAC should engage leading scientific, economic, and technological experts in this important effort. The report's recommendations should be addressed to the peoples and governments of Africa, relevant international policymakers, and the global scientific community. I would also welcome specific action proposals that could contribute to food security in Africa through a global collaboration of governments, civil society, and the corporate sectors. I urge you to consult with the Food and Agriculture Organization in the preparation of the report.

I very much look forward to receiving from the IAC a report that sets out how, concretely, the scientific community can work with farmers, governments and industry to avert a clear risk of famine for many tens of millions of people in Africa.

With very good wishes,

Yours sincerely,

Kofi A. Annan

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 (Omore 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 Counseil 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.

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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

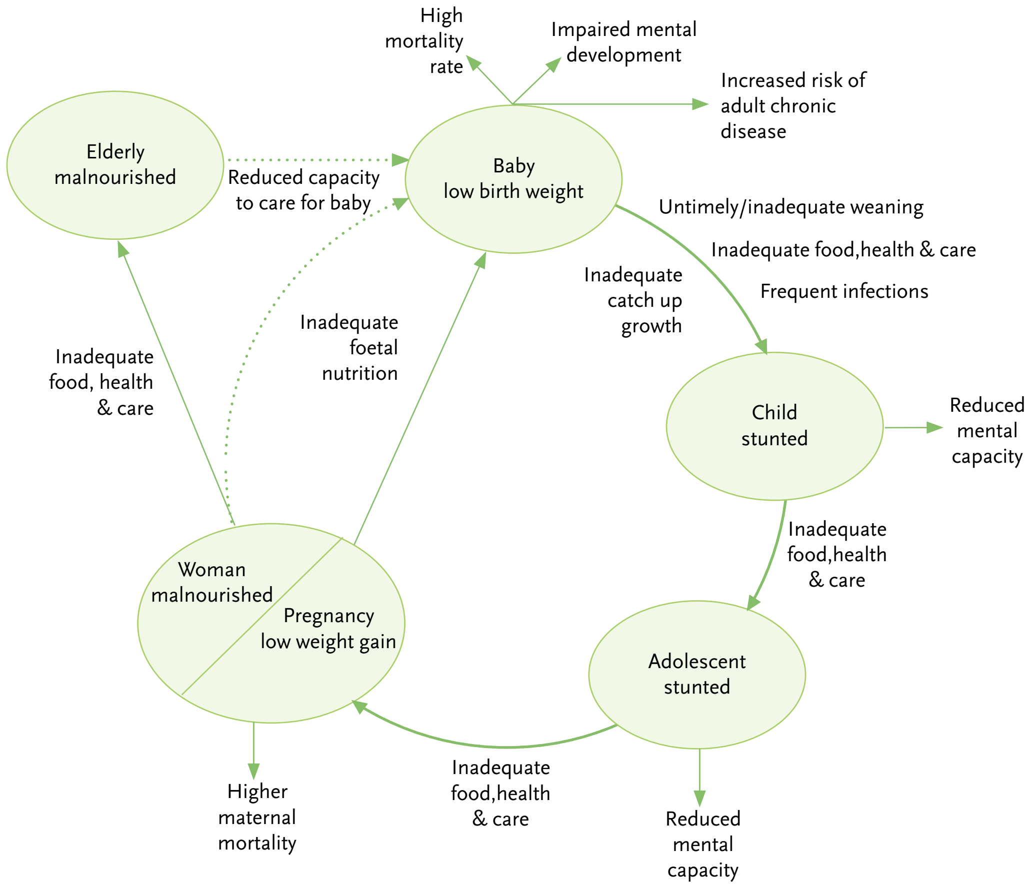

Figure 2.1 The nutritional challenge over the life cycle.
Source: World Health Organization (1997).

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 Millenium 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 beenlower. 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.

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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 (LGA), 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).

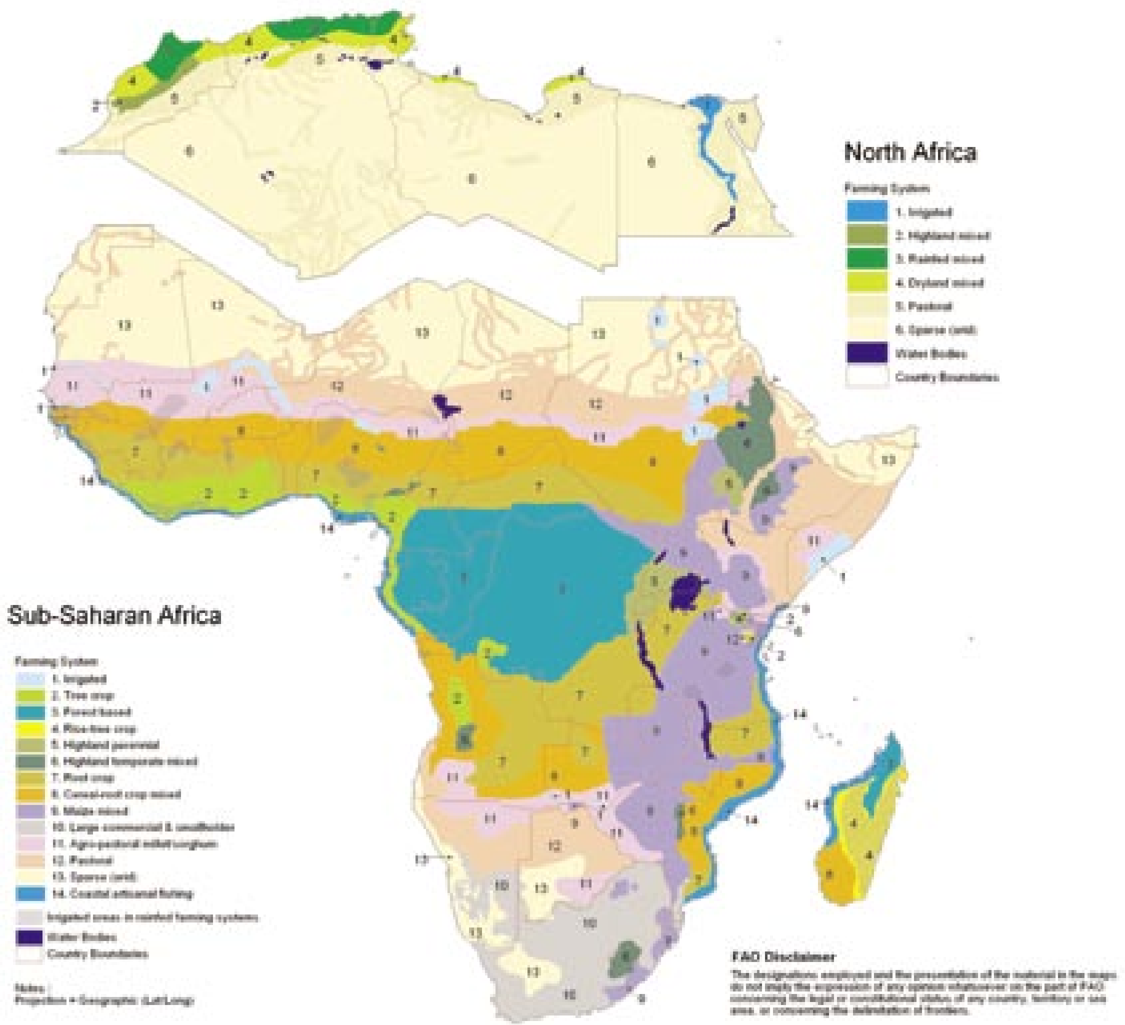


Figure 3.1 African farming systems according to Dixon et al. (2001)

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 fertilizer 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 requirements. 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.

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.

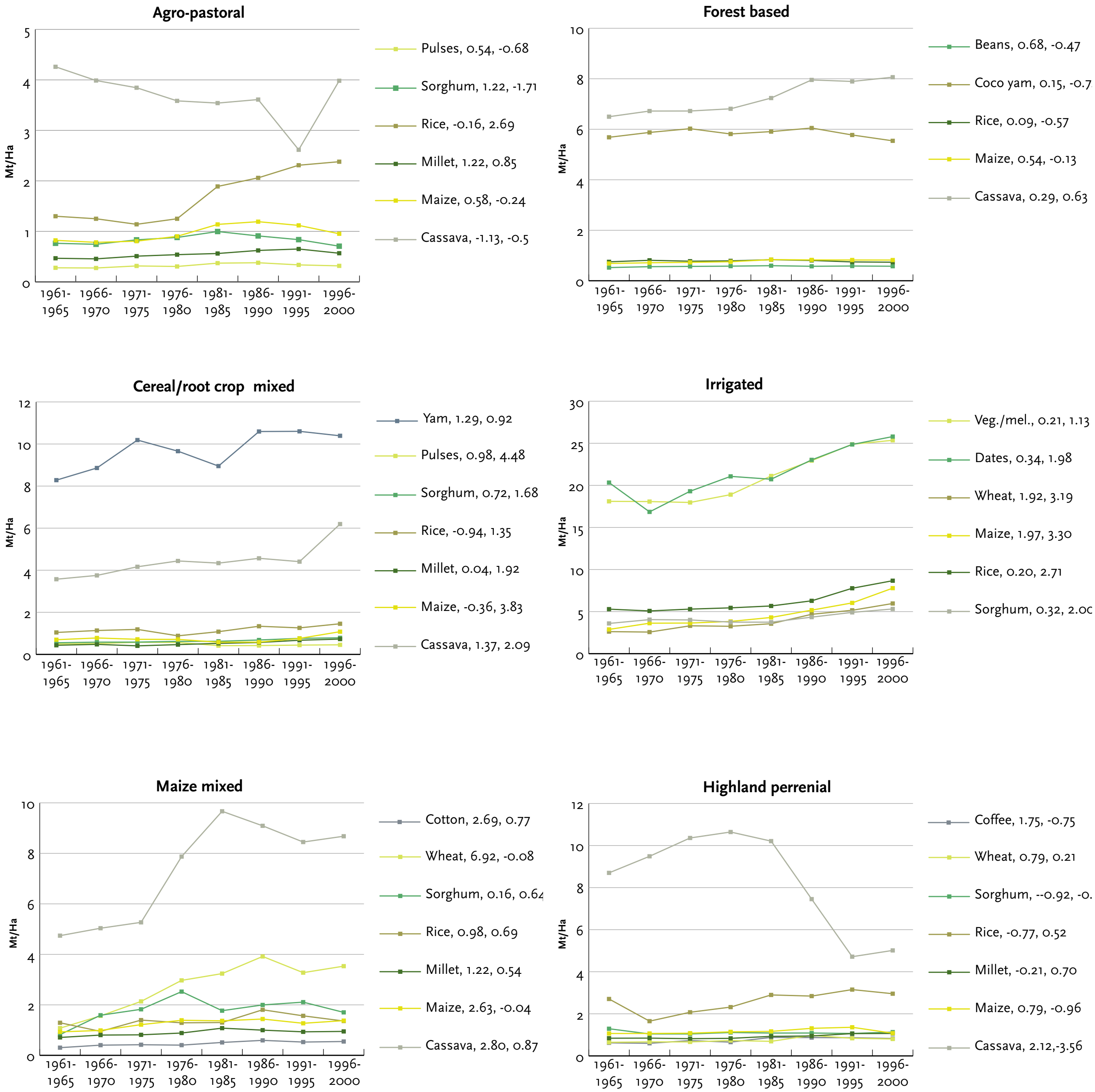
A range of factors underlies the productivity trends described above. In this chapter factors that impact yield across the major systems are studied. Chapter 4 describes more closely the specific technical constraints that limit productivity of the dominant crops in the priority systems and that research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

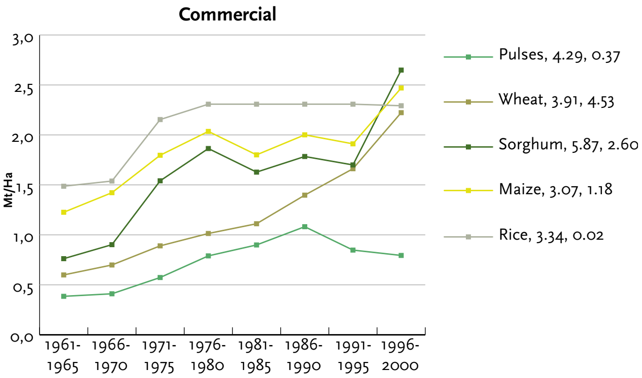
The production ecological approach

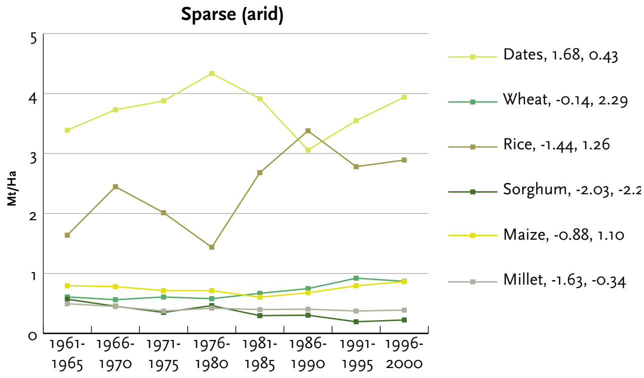
A production ecological approach disentangles *growth- and yield-defining factors* (genetic potential and solar radiation), *growth- and yield-limiting factors* (water and nutrients), and *growth- and yield-reducing factors* (weeds, pests, and diseases) in agricultural-production systems. This approach

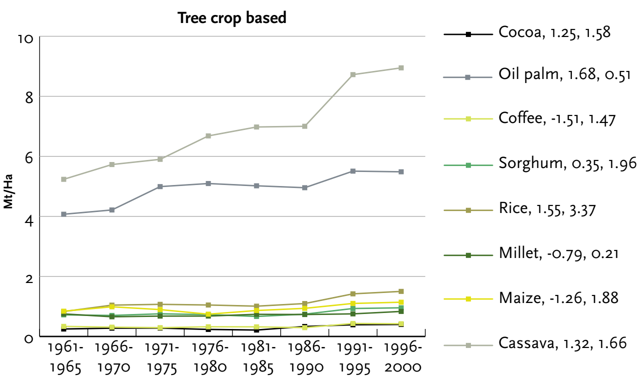
Figure 3.2 Land productivity trends of the major commodities in African farming systems

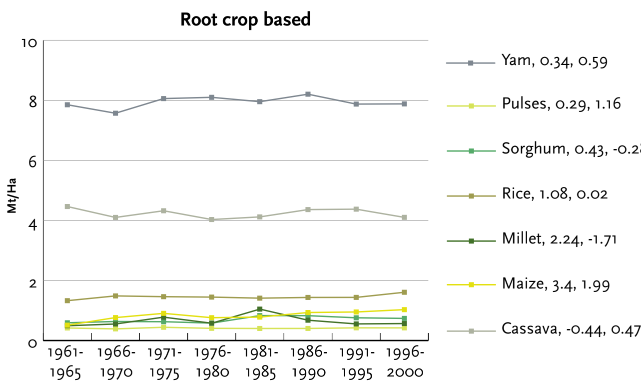
Source: FAOSTAT (2003). The numbers in the legend refer to the average percentage of annual yield increase in the period 1961-1980 and 1981-2000, respectively.




Commercial
Mt/Ha
3,0
2,5
2,0
1,5
1,0
0,5
0,0
1961-1965
1966-1970
1971-1975
1976-1980
1981-1985
1986-1990
1991-1995
1996-2000
Pulses, 4.29, 0.37
Wheat, 3.91, 4.53
Sorghum, 5.87, 2.60
Maize, 3.07, 1.18
Rice, 3.34, 0.02


Sparse (arid)
Mt/Ha
5
4
3
2
1
0
1961-1965
1966-1970
1971-1975
1976-1980
1981-1985
1986-1990
1991-1995
1996-2000
Dates, 1.68, 0.43
Wheat, -0.14, 2.29
Rice, -1.44, 1.26
Sorghum, -2.03, -2.2
Maize, -0.88, 1.10
Millet, -1.63, -0.34


Tree crop based
Mt/Ha
10
8
6
4
2
0
1961-1965
1966-1970
1971-1975
1976-1980
1981-1985
1986-1990
1991-1995
1996-2000
Cocoa, 1.25, 1.58
Oil palm, 1.68, 0.51
Coffee, -1.51, 1.47
Sorghum, 0.35, 1.96
Rice, 1.55, 3.37
Millet, -0.79, 0.21
Maize, -1.26, 1.88
Cassava, 1.32, 1.66


Root crop based
Mt/Ha
10
8
6
4
2
0
1961-1965
1966-1970
1971-1975
1976-1980
1981-1985
1986-1990
1991-1995
1996-2000
Yam, 0.34, 0.59
Pulses, 0.29, 1.16
Sorghum, 0.43, -0.2
Rice, 1.08, 0.02
Millet, 2.24, -1.71
Maize, 3.4, 1.99
Cassava, -0.44, 0.47

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).

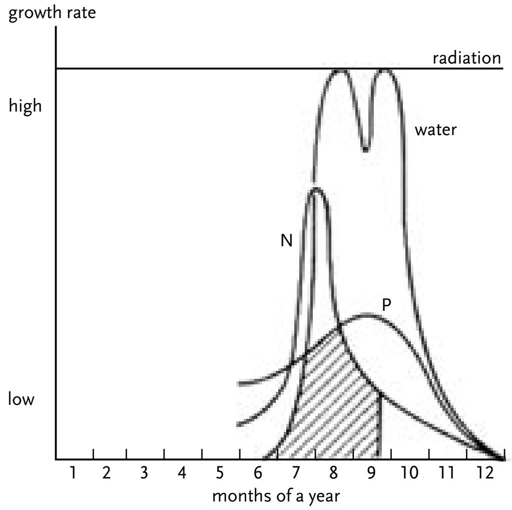


Figure 3.3 The relative impact of radiation, water, nitrogen and phosphorus growth of annual grasses in the Sahel. The graph is a schematic representation based on field observations.

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-

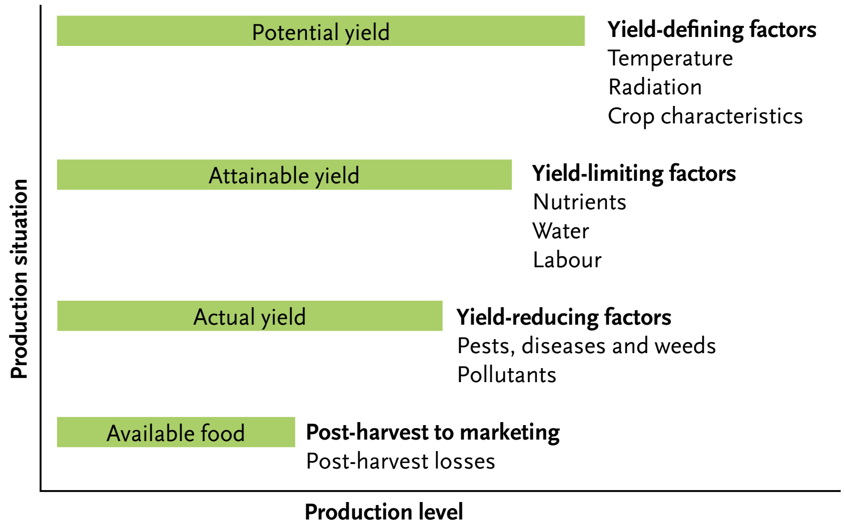


Figure 3.4 Principles of production ecology and factors affecting growth and yield and food availability. The graph represents technical constraints. The actual input levels will be determined by economic considerations.

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.

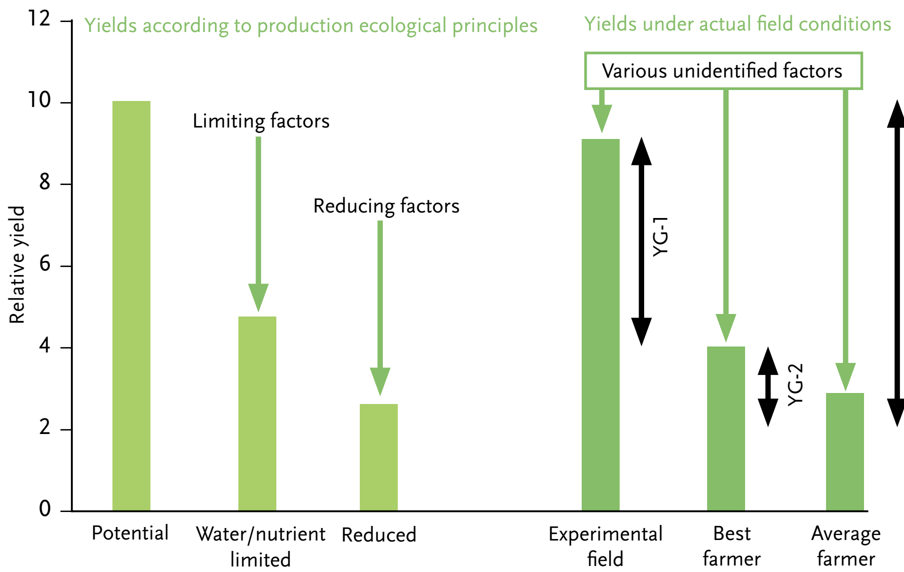


Figure 3.5 Yields analyzed according to production ecological principles and under actual field conditions.

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 nutrient 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.

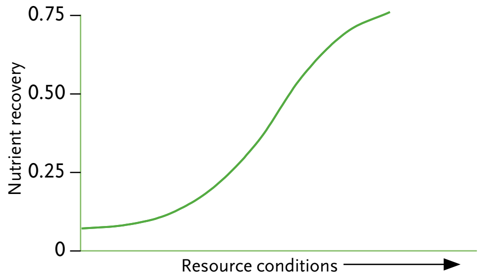


Figure 3.6 Schematic relation between nutrient recovery and agro-ecological conditions.

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 (Penning 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 Serpan'ié, 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-

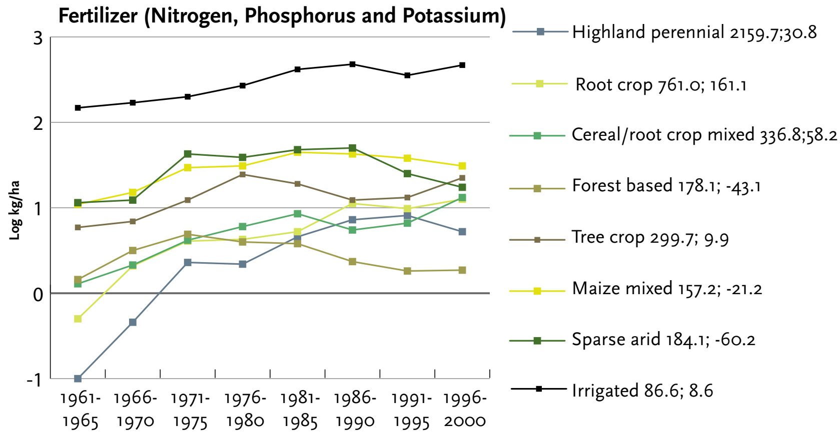


Figure 3.7 Trends in the use of fertilizers in farming systems in Africa.
Note: Figures in the legend represent total percentage change in fertilizer use for two periods – 1961/65-1976/80 and 1981/85-1996/2000). *Source*: FAO (2003)

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

	Agricultural area (1,000 ha)		
Farming systems	**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

	Percentage rainfed			
Region/commodity	**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 per100 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 Zhuand 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

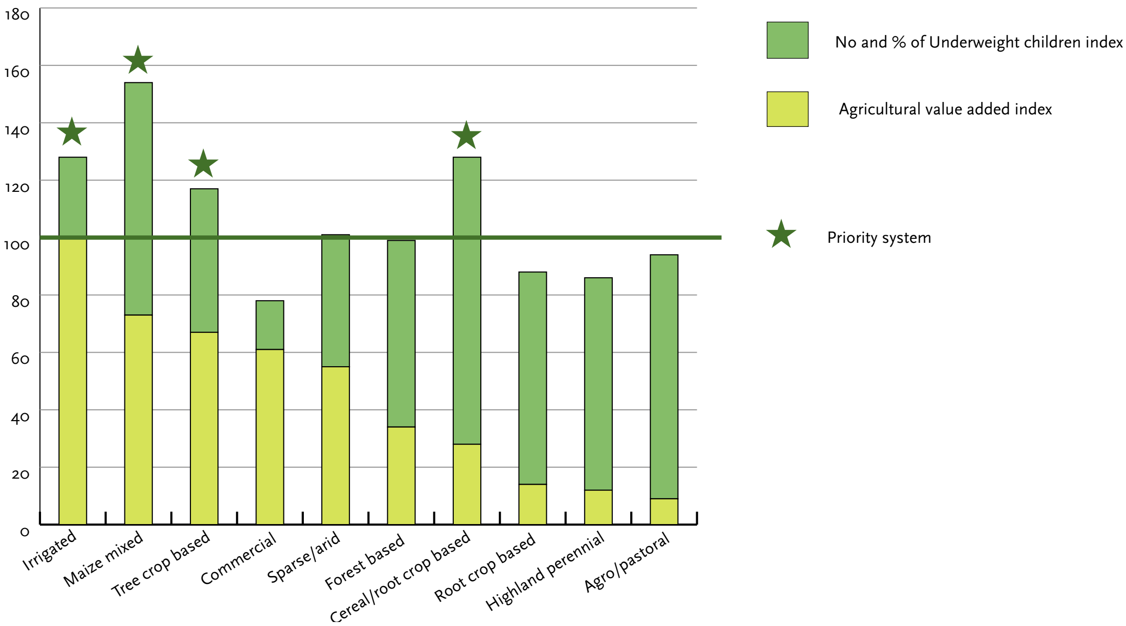
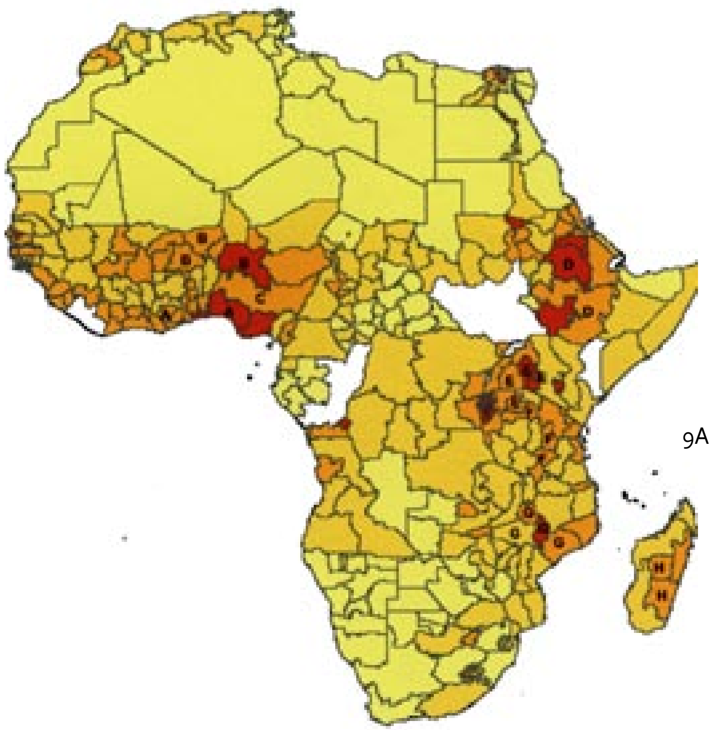


Figure 3.8 Characteristics of the priority systems (Dixon et al., 2001) and the indices as described in Table 3.5.

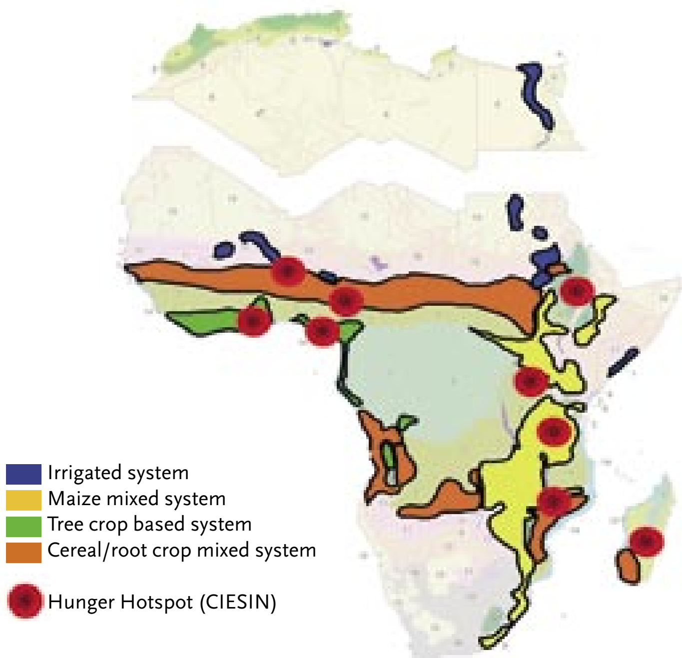
and number of underweight children are assigned equal weights. This composite underweight pre-school children index is plotted with the agricultural added value index in Figure 3.8.

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

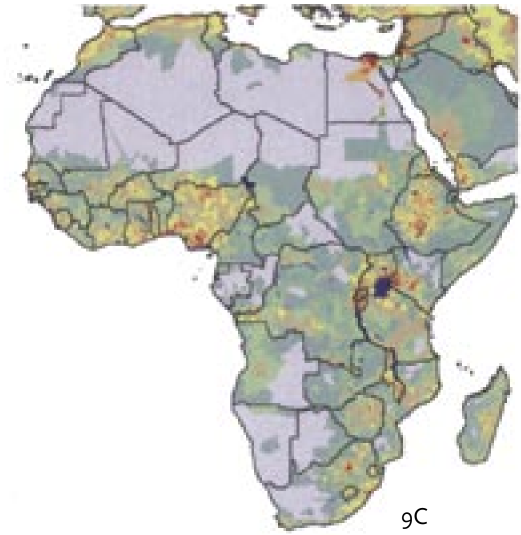
Figure 3.9 Population density of underweight children under five and proposed hunger hotspots (A), proposed hunger hotspots overlayed with farming systems (B), population density in 1995 (C), soil constraints combined (D), soil texture constraints (E) and soil fertility constraints (F). *Sources*: CIESIN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



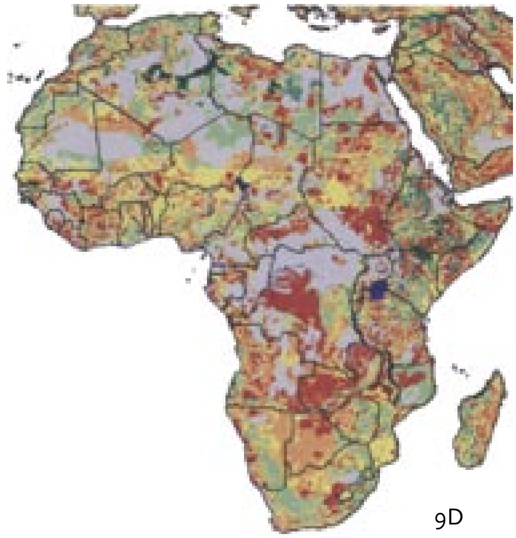
9A



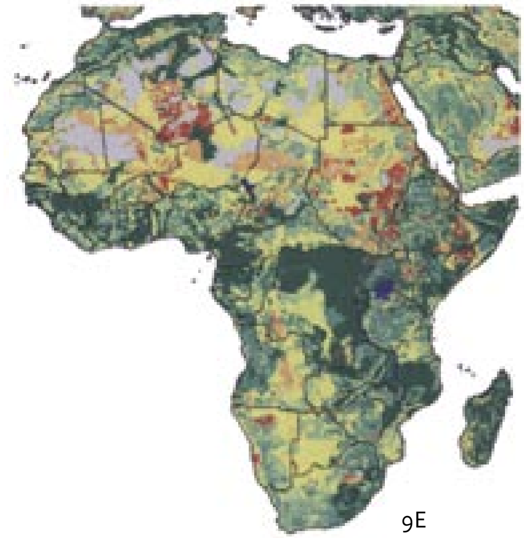
9B



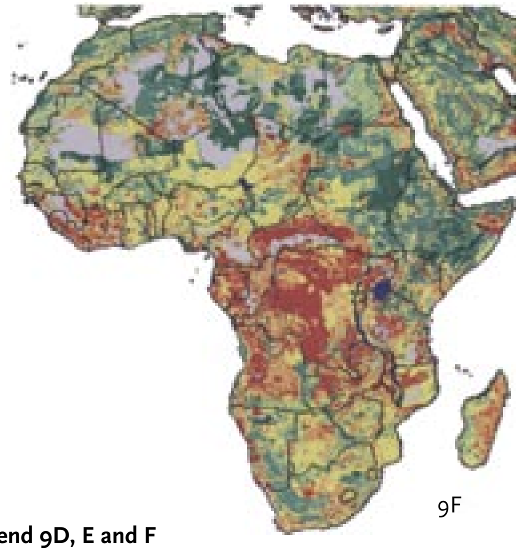
9C



9D



9E



9F

Legend 9C

- Unidentified
- <= 1 pers/km^2
- 1-5 pers/km^2
- 5-10 pers/km^2
- 10-20 pers/km^2
- 20-50 pers/km^2
- 50-100 pers/km^2
- 100-200 pers/km^2
- 200-500 pers/km^2
- 500-1000 pers/km^2
- > 1000 pers/km^2
- 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 densily 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.

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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

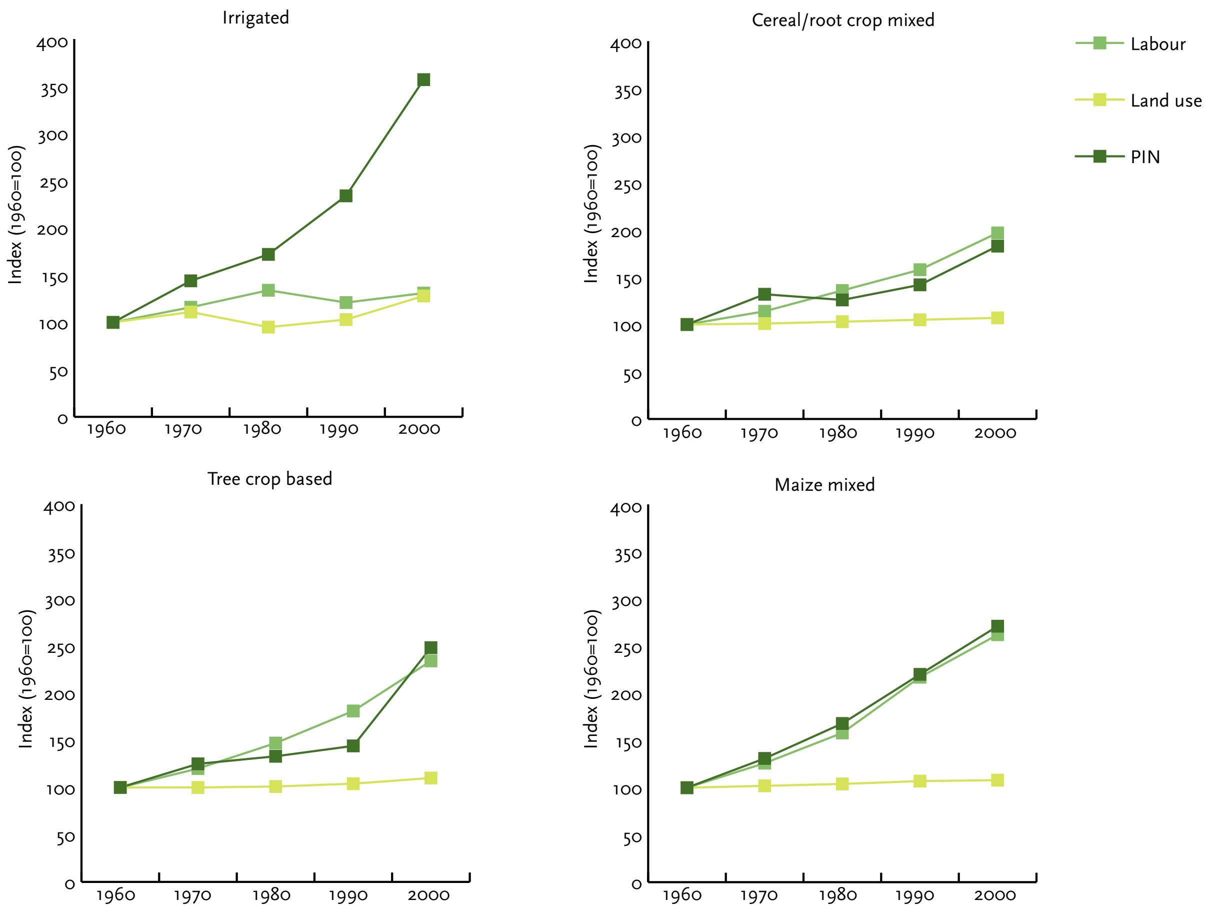

Figure 4.1 Changes in the total agricultural (crop plus livestock) production index number (PIN), agricultural land use (arable land, permanent crops and permanent pasture) and labour input in the four priority systems. *Source*: FAO (2003).

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.

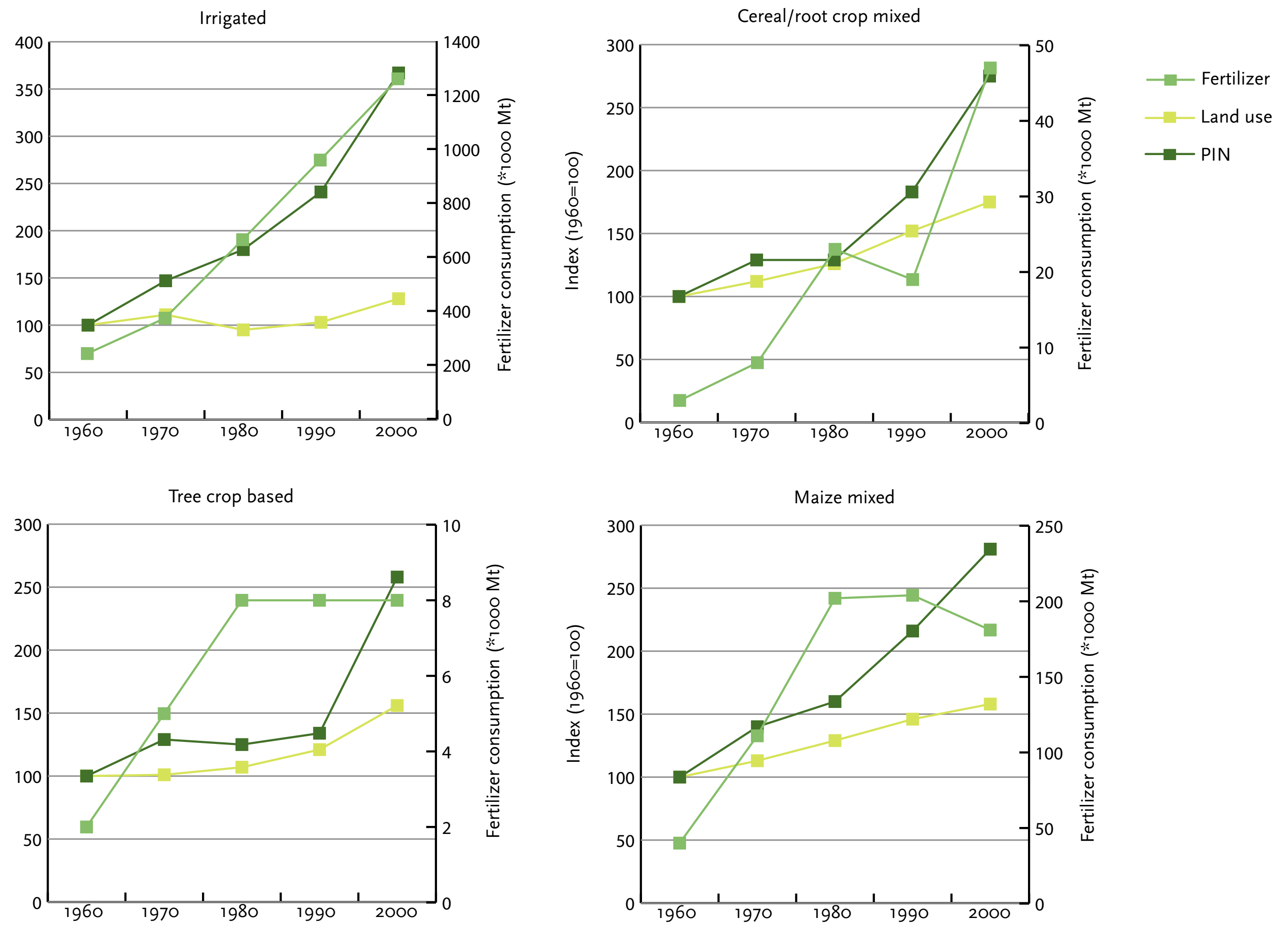

Figure 4.2 Changes in the crop production index number (PIN), crop land use (arable land and permanent crops) and fertilizer use in the four priority systems. *Source*: FAO (2003).

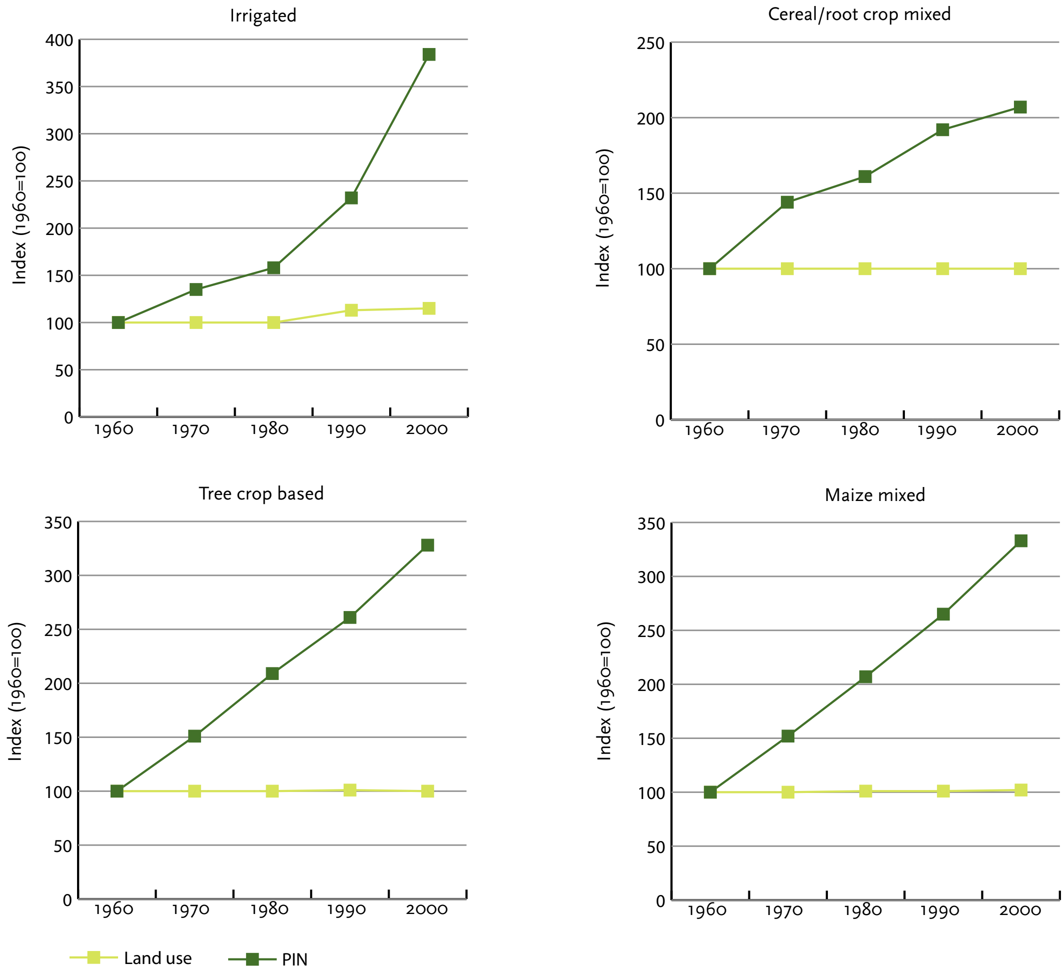

Figure 4.3 Changes in the livestock production index number (PIN) and non-crop land use (permanent pasture) in the four priority systems. *Source*: FAO (2003).

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

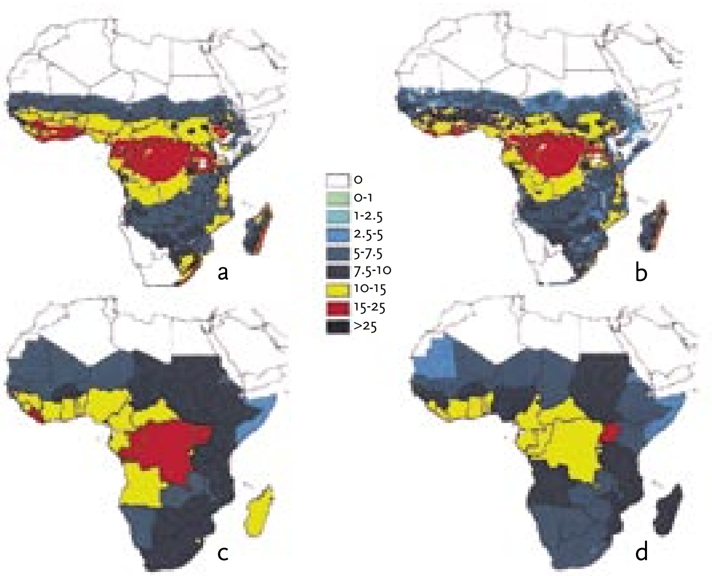

Figure 4.4 Calculated potential (a) and water-limited (b) yields (tonnes per hectare). The upper maps represent the estimations per grid cell of 5x5 minutes. The maps below are the weighted averages per country for agricultural land area (a' and b'). *Source*: Bindraban et al. (1999, 2000).

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.

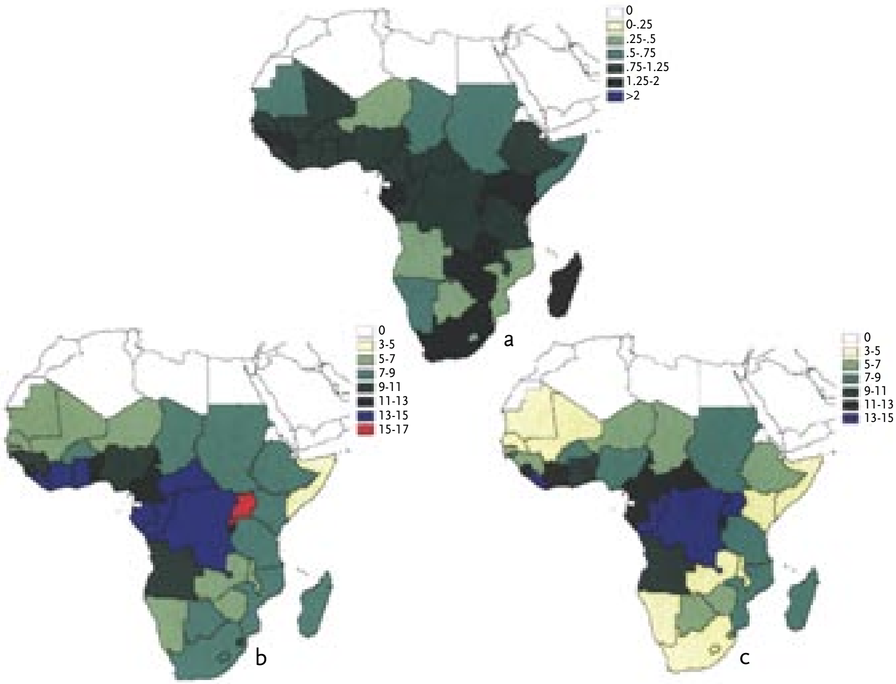

Figure 4.5 Actual average cereal yields at the national level are presented in map a. The difference between these yields with the potential yield are presented in map b, while map c presents the difference with the water-limited yield (tonnes per hectare). *Source*: Bindraban et al. (1999).

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 – ome 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.

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	*Ectoparasites*
Contagious bovine pleuro-pneumonia	*Gastro-intestinal parasitism*
Dermatophilosis	Haemonchosis
Ectoparasites	Infectious coryza
Gastro-intestinal parasitism	Newcastle disease
Heartwater	Neonatal mortality
Liver fluke (fascioliasis)	Nutritional/micronutrient deficiencies
Respiratory complexes	*Respiratory complexes*
Trypanosomosis	Rift valley fever

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

Box 4.4 Lethal animal diseases constrain production

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).

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 (Kaptesky, 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 resource 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 (Breman 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 direct transfer to companion crops. Direct transfer of nitrogren 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; Dobereiner, 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 Dobereiner 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 toti-potency 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/m²	Grain yield (tonnes/ha)
Control	0	23.2	0.55
Imazapyr	30	4.0	2.50
Imazapyr	45	1.4	2.72

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.

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.

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

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 cucurbit 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.

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.

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. ufficient 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 nutriceutical 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-