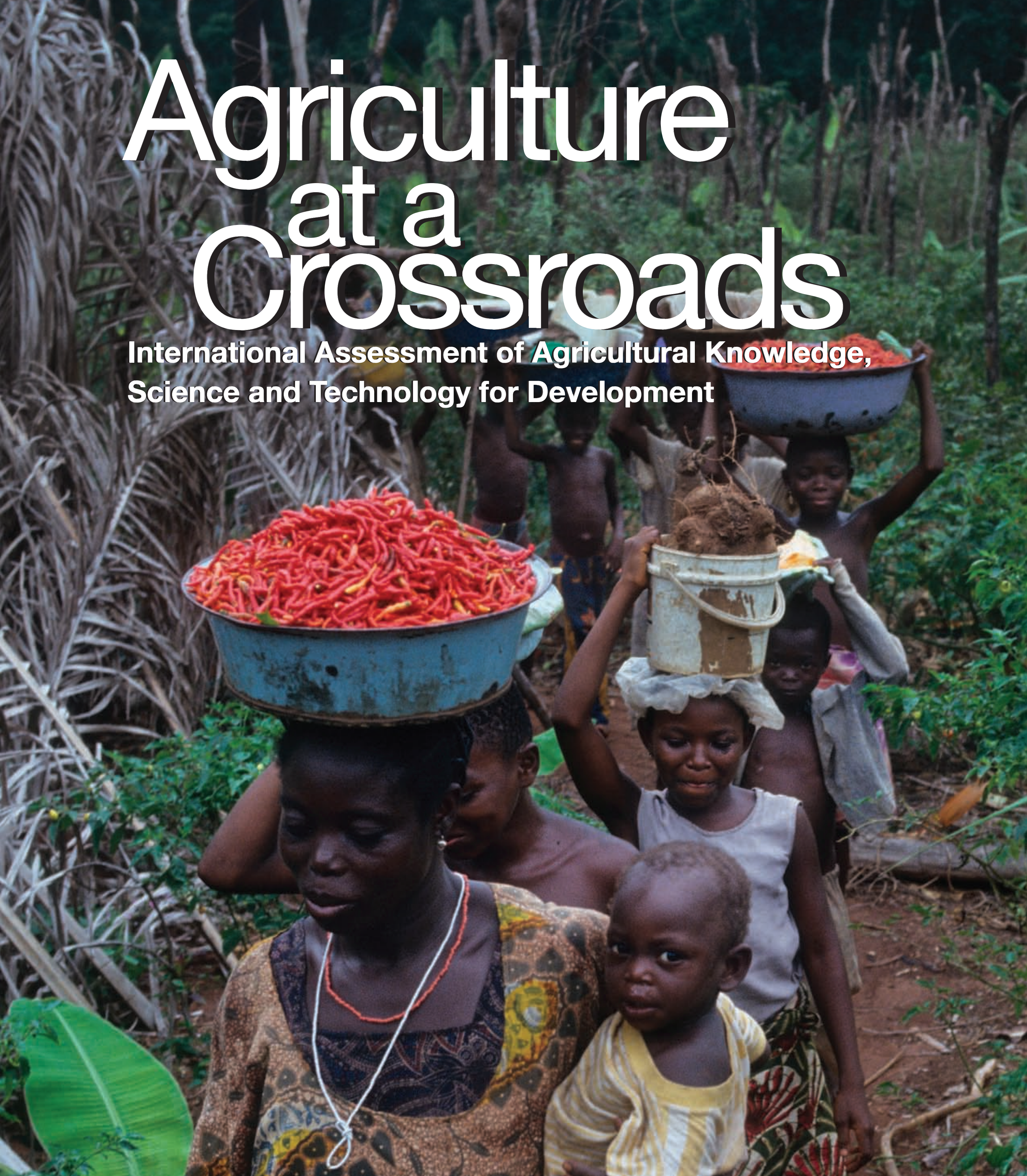
Agriculture at a Crossroads

International Assessment of Agricultural Knowledge, Science and Technology for Development



IAASTD

VOLUME V

Sub-Saharan Africa

IAASTD

International Assessment of Agricultural Knowledge, Science and Technology for Development

Sub-Saharan Africa (SSA) Report

IAASTD

International Assessment of Agricultural Knowledge, Science and Technology for Development

UNDP

UNEP

UNESCO

THE WORLD BANK

W.H.O. O.M.S.

WHO

GLOBAL ENVIRONMENT FACILITY

IAASTD

International Assessment of Agricultural Knowledge, Science and Technology for Development

Sub-Saharan Africa (SSA) Report

Edited by

Beverly D. McIntyre
IAASTD Secretariat

Hans R. Herren
Millennium Institute

Judi Wakhungu
African Centre for Technology Studies

Robert T. Watson
University of East Anglia

Library of Congress Cataloging-in-Publication data.

International assessment of agricultural knowledge, science and technology for development (IAASTD) : Sub-Saharan Africa (SSA) report / edited by Beverly D. McIntyre . . . [et al.].
p. cm.
Includes bibliographical references and index.
ISBN 978-1-59726-540-9 (cloth : alk. paper) —
ISBN 978-1-59726-541-6 (pbk. : alk. paper)
1. Agriculture—Africa, Sub-Saharan—International cooperation.
2. Sustainable development—Africa, Sub-Saharan. I. McIntyre, Beverly D. II. Title: Sub-Saharan Africa (SSA) report.
HD1428.I546 2008
338.967′07—dc22 2008046044

British Cataloguing-in-Publication data available.

Printed on recycled, acid-free paper

Interior and cover designs by Linda McKnight, McKnight Design, LLC.

Manufactured in the United States of America

10 9 8 7 6 5 4 3 2 1

Contents

Statement by Governments

All countries present at the final intergovernmental plenary session held in Johannesburg, South Africa in April 2008 welcome the work of the IAASTD and the uniqueness of this independent multistakeholder and multidisciplinary process, and the scale of the challenge of covering a broad range of complex issues. The Governments present recognize that the Global and Sub-Global Reports are the conclusions of studies by a wide range of scientific authors, experts and development specialists and while presenting an overall consensus on the importance of agricultural knowledge, science and technology for development also provide a diversity of views on some issues.

All countries see these Reports as a valuable and important contribution to our understanding on agricultural knowledge, science and technology for development recognizing the need to further deepen our understanding of the challenges ahead. This Assessment is a constructive initiative and important contribution that all governments need to take forward to ensure that agricultural knowledge, science and technology fulfills its potential to meet the development and sustainability goals of the reduction of hunger and poverty, the improvement of rural livelihoods and human health, and facilitating equitable, socially, environmentally and economically sustainable development.

In accordance with the above statement, the following governments accept the sub-Saharan Africa Report:

Benin, Botswana, Cameroon, Democratic Republic of Congo, Ethiopia, Gambia, Ghana, Kenya, Mozambique, Namibia, Nigeria, Senegal, Swaziland, United Republic of Tanzania, Togo, Uganda, Zambia (17 countries).

Foreword

The objective of the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) was to assess the impacts of past, present and future agricultural knowledge, science and technology on the:

- reduction of hunger and poverty,
- improvement of rural livelihoods and human health, and
- equitable, socially, environmentally and economically sustainable development.

The IAASTD was initiated in 2002 by the World Bank and the Food and Agriculture Organization of the United Nations (FAO) as a global consultative process to determine whether an international assessment of agricultural knowledge, science and technology was needed. Mr. Klaus Töepfer, Executive Director of the United Nations Environment Programme (UNEP) opened the first Intergovernmental Plenary (30 August-3 September 2004) in Nairobi, Kenya, during which participants initiated a detailed scoping, preparation, drafting and peer review process.

The outputs from this assessment are a Global and five Sub-Global reports; a global and five Sub-Global Summaries for Decision Makers; and a cross-cutting Synthesis Report with an Executive Summary. The Summaries for Decision Makers and the Synthesis Report specifically provide options for action to governments, international agencies, academia, research organizations and other decision makers around the world.

The reports draw on the work of hundreds of experts from all regions of the world who have participated in the preparation and peer review process. As has been customary in many such global assessments, success depended first and foremost on the dedication, enthusiasm and cooperation of these experts in many different but related disciplines. It is the synergy of these inter-related disciplines that permitted IAASTD to create a unique, interdisciplinary regional and global process.

We take this opportunity to express our deep gratitude to the authors and reviewers of all of the reports—their dedication and tireless efforts made the process a success. We thank the Steering Committee for distilling the outputs of the consultative process into recommendations to the Plenary, the IAASTD Bureau for their advisory role during the assessment and the work of those in the extended Secretariat. We would specifically like to thank the cosponsoring organizations of the Global Environment Facility (GEF) and the World Bank for their financial contributions as well as the FAO, UNEP, and the United Nations Educational, Scientific and Cultural Organization (UNESCO) for their continued support of this process through allocation of staff resources.

We acknowledge with gratitude the governments and organizations that contributed to the Multidonor Trust Fund (Australia, Canada, the European Commission, France, Ireland, Sweden, Switzerland, and the United Kingdom) and the United States Trust Fund. We also thank the governments who provided support to Bureau members, authors and reviewers in other ways. In addition, Finland provided direct support to the Secretariat. The IAASTD was especially successful in engaging a large number of experts from developing countries and countries with economies in transition in its work; the Trust Funds enabled financial assistance for their travel to the IAASTD meetings.

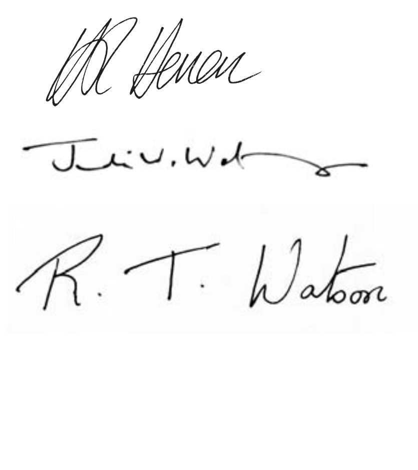
We would also like to make special mention of the organizations who hosted the regional coordinators and staff and provided assistance in management and time to ensure success of this enterprise: the African Center for Technology Studies (ACTS) in Kenya, the Inter-American Institute for Cooperation on Agriculture (IICA) in Costa Rica, the International Center for Agricultural Research in the Dry Areas (ICARDA) in Syria, and the WorldFish Center in Malaysia.

The final Intergovernmental Plenary in Johannesburg, South Africa was opened on 7 April 2008 by Achim Steiner, Executive Director of UNEP. This Plenary saw the acceptance of the Reports and the approval of the Summaries for Decision Makers and the Executive Summary of the Synthesis Report by an overwhelming majority of governments.

Signed:

Co-chairs
Hans H. Herren,
Judi Wakhungu

Director
Robert T. Watson



Preface

In August 2002, the World Bank and the Food and Agriculture Organization (FAO) of the United Nations initiated a global consultative process to determine whether an international assessment of agricultural knowledge, science and technology (AKST) was needed. This was stimulated by discussions at the World Bank with the private sector and nongovernmental organizations (NGOs) on the state of scientific understanding of biotechnology and more specifically transgenics. During 2003, eleven consultations were held, overseen by an international multistakeholder steering committee and involving over 800 participants from all relevant stakeholder groups, e.g., governments, the private sector and civil society. Based on these consultations the steering committee recommended to an Intergovernmental Plenary meeting in Nairobi in September 2004 that an international assessment of the role of AKST in reducing hunger and poverty, improving rural livelihoods and facilitating environmentally, socially and economically sustainable development was needed. The concept of an International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) was endorsed as a multi-thematic, multi-spatial, multi-temporal intergovernmental process with a multistakeholder Bureau cosponsored by the FAO, the Global Environment Facility (GEF), United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Bank and World Health Organization (WHO).

The IAASTD's governance structure is a unique hybrid of the Intergovernmental Panel on Climate Change (IPCC) and the nongovernmental Millennium Ecosystem Assessment (MA). The stakeholder composition of the Bureau was agreed at the Intergovernmental Plenary meeting in Nairobi; it is geographically balanced and multistakeholder with 30 government and 30 civil society representatives (NGOs, producer and consumer groups, private sector entities and international organizations) in order to ensure ownership of the process and findings by a range of stakeholders.

About 400 of the world's experts were selected by the Bureau, following nominations by stakeholder groups, to prepare the IAASTD Report (comprised of a Global and 5 Sub-Global assessments). These experts worked in their own capacity and did not represent any particular stakeholder group. Additional individuals, organizations and governments were involved in the peer review process.

The IAASTD development and sustainability goals were endorsed at the first Intergovernmental Plenary and are consistent with a subset of the UN Millennium Development Goals (MDGs): the reduction of hunger and poverty, the improvement of rural livelihoods and human health, and facilitating equitable, socially, environmentally and economically sustainable development. Realizing these goals requires acknowledging the multifunctionality of agriculture: the challenge is to simultaneously meet development and sustainability goals while increasing agricultural production.

Meeting these goals has to be placed in the context of a rapidly changing world of urbanization, growing inequities, human migration, globalization, changing dietary preferences, climate change, environmental degradation, a trend toward biofuels and an increasing population. These conditions are affecting local and global food security and putting pressure on productive capacity and ecosystems. Hence there are unprecedented challenges ahead in providing food within a global trading system where there are other competing uses for agricultural and other natural resources. AKST alone cannot solve these problems, which are caused by complex political and social dynamics, but it can make a major contribution to meeting development and sustainability goals. Never before has it been more important for the world to generate and use AKST.

Given the focus on hunger, poverty and livelihoods, the IAASTD pays special attention to the current situation, issues and potential opportunities to redirect the current AKST system to improve the situation for poor rural people, especially small-scale farmers, rural laborers and others with limited resources. It addresses issues critical to formulating policy and provides information for decision makers confronting conflicting views on contentious issues such as the environmental consequences of productivity increases, environmental and human health impacts of transgenic crops, the consequences of bioenergy development on the environment and on the long-term availability and price of food, and the implications of climate change on agricultural production. The Bureau agreed that the scope of the assessment needed to go beyond the narrow confines of science and technology (S&T) and should encompass other types of relevant knowledge (e.g., knowledge held by agricultural producers, consumers and end users) and that it should also assess the role of institutions, organizations, governance, markets and trade.

The IAASTD is a multidisciplinary and multistakeholder enterprise requiring the use and integration of information, tools and models from different knowledge paradigms including local and traditional knowledge. The IAASTD does not advocate specific policies or practices; it assesses the major issues facing AKST and points towards a range of AKST options for action that meet development and sustainability goals. It is policy relevant, but not policy prescriptive. It integrates scientific information on a range of topics that are critically interlinked, but often addressed independently, i.e., agriculture, poverty, hunger, human health, natural resources, environment, development and innovation. It will enable decision makers to bring a richer base of knowledge to bear on policy and management decisions on issues previously viewed in isolation. Knowledge gained from historical analysis (typically the past 50 years) and an analysis of some future development alternatives to 2050 form the basis for assessing options for action on science and technology, capacity development, institutions and policies, and investments.

The IAASTD is conducted according to an open, transparent, representative and legitimate process; is evidence-based; presents options rather than recommendations; assesses different local, regional and global perspectives; presents different views, acknowledging that there can be more than one interpretation of the same evidence based on different worldviews; and identifies the key scientific uncertainties and areas on which research could be focused to advance development and sustainability goals.

The IAASTD is composed of a Global assessment and five Sub-Global assessments: Central and West Asia and North Africa – CWANA; East and South Asia and the Pacific – ESAP; Latin America and the Caribbean – LAC; North America and Europe – NAE; and Sub-Saharan Africa – SSA. It (1) assesses the generation, access, dissemination and use of public and private sector AKST in relation to the goals, using local, traditional and formal knowledge; (2) analyzes existing and emerging technologies, practices, policies and institutions and their impact on the goals; (3) provides information for decision makers in different civil society, private and public organizations on options for improving policies, practices, institutional and organizational arrangements to enable AKST to meet the goals; (4) brings together a range of stakeholders (consumers, governments, international agencies and research organizations, NGOs, private sector, producers, the scientific community) involved in the agricultural sector and rural development to share their experiences, views, understanding and vision for the future; and (5) identifies options for future public and private investments in AKST. In addition, the IAASTD will enhance local and regional capacity to design, implement and utilize similar assessments.

In this assessment agriculture is used to include production of food, feed, fuel, fiber and other products and to include all sectors from production of inputs (e.g., seeds and fertilizer) to consumption of products. However, as in all assessments, some topics were covered less extensively than others (e.g., livestock, forestry, fisheries and the agricultural sector of small island countries, and agricultural engineering), largely due to the expertise of the selected authors.

The IAASTD draft Report was subjected to two rounds of peer review by governments, organizations and individuals. These drafts were placed on an open access Web site and open to comments by anyone. The authors revised the drafts based on numerous peer review comments, with the assistance of review editors who were responsible for ensuring the comments were appropriately taken into account. One of the most difficult issues authors had to address was criticisms that the report was too negative. In a scientific review based on empirical evidence, this is always a difficult comment to handle, as criteria are needed in order to say whether something is negative or positive. Another difficulty was responding to the conflicting views expressed by reviewers. The difference in views was not surprising given the range of stakeholder interests and perspectives. Thus one of the key findings of the IAASTD is that there are diverse and conflicting interpretations of past and current events, which need to be acknowledged and respected.

The Global and Sub-Global Summaries for Decision Makers and the Executive Summary of the Synthesis Report were approved at an Intergovernmental Plenary in April 2008. The Synthesis Report integrates the key findings from the Global and Sub-Global assessments, and focuses on eight Bureau-approved topics: bioenergy; biotechnology; climate change; human health; natural resource management; traditional knowledge and community based innovation; trade and markets; and women in agriculture.

The IAASTD builds on and adds value to a number of recent assessments and reports that have provided valuable information relevant to the agricultural sector, but have not specifically focused on the future role of AKST, the institutional dimensions and the multifunctionality of agriculture. These include: FAO State of Food Insecurity in the World (yearly); InterAcademy Council Report: Realizing the Promise and Potential of African Agriculture (2004); UN Millennium Project Task Force on Hunger (2005); Millennium Ecosystem Assessment (2005); CGIAR Science Council Strategy and Priority Setting Exercise (2006); Comprehensive Assessment of Water Management in Agriculture: Guiding Policy Investments in Water, Food, Livelihoods and Environment (2007); Intergovernmental Panel on Climate Change Reports (2001 and 2007); UNEP Fourth Global Environmental Outlook (2007); World Bank World Development Report: Agriculture for Development (2008); IFPRI Global Hunger Indices (yearly); and World Bank Internal Report of Investments in SSA (2007).

Financial support was provided to the IAASTD by the cosponsoring agencies, the governments of Australia, Canada, Finland, France, Ireland, Sweden, Switzerland, US and UK, and the European Commission. In addition, many organizations have provided in-kind support. The authors and review editors have given freely of their time, largely without compensation.

The Global and Sub-Global Summaries for Decision Makers and the Synthesis Report are written for a range of stakeholders, i.e., government policy makers, private sector, NGOs, producer and consumer groups, international organizations and the scientific community. There are no recommendations, only options for action. The options for action are not prioritized because different options are actionable by different stakeholders, each of whom has a different set of priorities and responsibilities and operate in different socioeconomic and political circumstances.

1

Setting the Scene: The Sub-Saharan Africa Context

Coordinating Lead Authors:
Amadou Diop (Senegal), Evelyne A. Lazaro (Tanzania)

Lead Authors:
Wellington Otieno (Kenya), Joseph Taabazuing (Ghana)

Contributing authors:
Nienke Beintema (Netherlands), Anna Stabrawa (Kenya)

Review Editor:
Davo Simplice Vodouhe (Benin)

Key messages

Key Messages

1. Sub-Saharan Africa has one of the world's fastest growing populations, but the growth rate of food production has not kept pace. This has led to a food deficit.

2. Agriculture is the dominant land use in the region with permanent pasture accounting for 35%, while arable and permanent cropland comprises only about 8% of the area.

3. Over 60% of the population of sub-Saharan Africa depends on agriculture for their livelihood and agriculture accounted for 29% of GDP on average between 1998-2000. The livelihood of the majority of the population, which is mostly poor, is being threatened by the rapid depletion of natural resources such as forests, and declining soil fertility. Because of its cross-cutting nature, land use management that minimizes degradation is a priority issue for the region.

4. The nature of farming is changing in many sub-Saharan African countries. As the farm population ages, rural male workers are migrating to urban areas, and many rural areas are becoming urbanized. Another key factor in the changing demographics is the prevalence of diseases, particularly HIV/AIDS and malaria.

5. Women play a central role in agricultural production and household well-being, growing 80% of staple foods. Males, however, are the primary decision makers.

6. Improving the productivity and the economic returns of agriculture has immediate effects on poverty and hunger. Research shows that for each 10% increase in small-scale agricultural productivity (which is the dominant base) in sub-Saharan Africa, almost 7 million people are moved above the dollar-a-day poverty line. The number of people living on less than US$1 per day actually increased from 227 million in 1990 to 303 million in 2002 because of population growth, even though the percentage of people living on less than US$1 per day in SSA declined slightly from 44.6% to 44%.

7. The social and economic consequences of malnutrition are widely felt, not only in the health sector but also in education, industry, agriculture, transport, human resources and the economy in general. Chronic hunger has decreased slightly (from 33% in 1990-1992 to 31% in 2001-2003) but the absolute number of people suffering from hunger has increased. Increased population growth has resulted in a decrease in the proportion of the population with chronic hunger. Malnutrition in children under five years was 30% between 1995-2002. There has not been much change in the extent of malnourishment in SSA: 31% of the population was undernourished between 1990-1992 and increased slightly to 32% between 2001-2003.

8. Rapid depletion of natural resources such as forests and declining soil fertility threatens the livelihoods of poor people. Land use and degradation are priority issues for the region because of their cross-cutting impacts on other resources and human activities, particularly agriculture. Soil moisture stress inherently constrains land productivity on 85% of soils in Africa and soil fertility degradation now places an additional human-induced limitation on productivity.

9. Sub-Saharan Africa is the most vulnerable region in the world to climate change. Climate variability is an important atmospheric phenomenon in sub-Saharan Africa, where climatic conditions are uncertain and display a high degree of variability. Analysis of long-term trends (1900-2005) indicates rising temperatures in Africa as a whole, as well as drying, or decreased precipitation. This change causes significant climatic disturbances in many parts of the continent, either inducing drought or flooding, or increasing sea temperatures, which lead to cyclones, particularly over the Indian Ocean.

10. With growing demand for water resources from all sectors, it is projected that by 2025, thirteen countries in sub-Saharan Africa will experience water stress and another ten countries will suffer from water scarcity. With global warming, changes in rainfall and temperature patterns are likely to be inevitable and will negatively affect water availability.

11. The principal threats to biodiversity in Africa include land use and land cover change, mainly through conversion of natural ecosystems, particularly forests and grasslands, to agricultural land and urban areas. It is likely that land clearing and deforestation will continue and hence threaten genetic diversity as species loss occurs.

1.1 IAASTD Conceptual Framework

The primary goal of the IAASTD is "to assess how we can reduce hunger and poverty, improve rural livelihoods and facilitate equitable, socially, environmentally and economically sustainable development through the generation, access to and use of agricultural knowledge, science, and technology." IAASTD uses a conceptual framework (Figure 1-1) that enables a systematic analysis and appraisal of the above challenges based on common concepts and terminology.

An assessment is a critical, objective evaluation and analysis of available information designed to meet user needs and to support decision-making. It is an application of experts' judgment of existing knowledge, including traditional and local knowledge, with a view to providing scientifically credible answers to policy-relevant questions, quantifying the level of confidence wherever possible.

Agriculture in this report is defined broadly to include agricultural systems consisting of crops, livestock and pastoralism, fisheries, biomass, agricultural goods and services, and land management activities such as forestry and agroforestry.

The conceptual framework describes the linkages between the elements of the framework and how they will be addressed. Direct drivers are: availability and management of natural resources, climate change, labour, energy and AKST use. Indirect drivers can be characterized as eco-

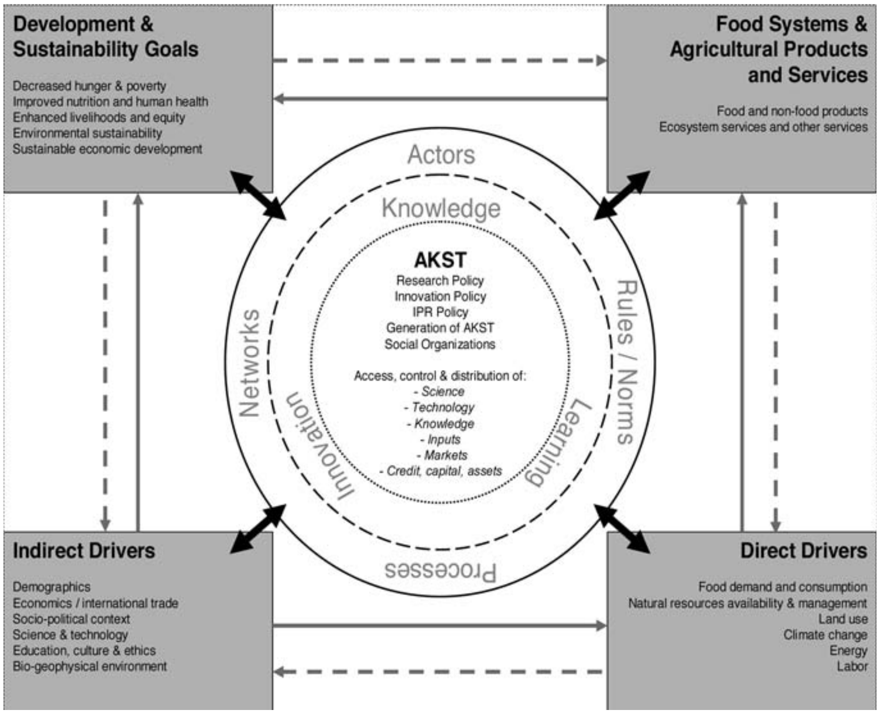


Figure 1-1. *IAASTD conceptual framework.*

nomic, demographic, educational, sociopolitical, infrastructural, and agricultural knowledge, science and technology. These drivers are described in detail in chapter 3. The assessment focuses on the interactions among the drivers in order to understand how to facilitate the achievement of development and sustainability goals.

In the following chapters, we look at AKST in relation to the development and sustainability goals of the IAASTD through the lens of a historical and current perspective (Chapters 2, 3). We then look at the next 50 years (Chapter 4) in order to provide decision makers with an assessment of options for achieving development and sustainability goals (Chapter 5).

1.2 The Sub-Saharan Africa Context

1.2.1 Environmental and natural resources

The diverse physical features of sub-Saharan Africa (SSA) present opportunities and constraints for agricultural development. Sub-Saharan Africa is endowed with a wealth of physical and biological natural resources which have sustained the region's growing population and helped fuel development (Lelo and Makenzi, 2000). The region has large deserts (e.g., the Kalahari covers $260x10^3$ km^2), high mountains (e.g., Mount Kilimanjaro at 5895 m), large rain forests (the Congo basin forest ecosystem covers 200 million ha and is second only to the Amazon) and rich mineral deposits (bauxite, cobalt diamond, phosphate rock, platinum-group metals, vermiculite and zirconium) (Yager et al., 2004; UNEP, 2006a,b). Nevertheless, this natural wealth is unevenly distributed, largely unexploited and has sometimes been a source of conflict. For example, mineral resources such as diamonds and oil deposits have been at the center of conflict as well as economic development (Lelo and Makenzi, 2000; UNEP, 2006a).

1.2.1.1 Land

Sub-Saharan Africa covers an area of 2.4 x 10^9 ha. Only about 8% of this land is arable and permanent cropland (Table 1-1). Over 60% of the population depends on agriculture for their livelihood (ILO, 2005; WRI, 2005). One of the largest expansions of cropland in sub-Saharan Africa in the last 20 years or so has been around the Great Lakes subregion of eastern Africa (Lepers et al., 2005).

Some of the main issues relating to land in SSA are land degradation and desertification, as well as inappropriate

Table 1-1. *Landuse in SSA (2000).*

Land-use	Cover (%)
Permanent pasture	35
Arable and permanent cropland	8
Forested (FAO estimates for 2000 >10% cover)	20
All other land	37
Total	100

Note: Sub-Saharan Africa includes Mauritania, Somalia and Sudan, and excludes Cape Verde, Comoros, Mauritius, Sao Tome and Principe, Seychelles and Swaziland, for which data is not available. Source: WRI, 2005.

and inequitable land-tenure systems that contribute to land degradation through unsustainable practices, declining soil fertility, poor land management and conservation, and the conversion of fragile natural habitats to agricultural and urban uses (UNEP, 2002a). Land use and degradation are priority issues for the region because of their cross-cutting impacts on other resources and human activities, particularly agriculture (UNEP, 2007a).

Land degradation is a loss of ecosystem function and services caused by disturbances from which the system cannot recover unaided. Land degradation, which includes soil erosion by wind or water, nutrient depletion, desertification, salinity caused by land-use and management, and chemical contamination and pollution, is broader than soil degradation, since land includes vegetation, water and microclimate (Bojo, 1996). Climate variability and unsustainable human activity are associated with land degradation (UNEP, 2007b). Approximately 65% of agricultural land, 35% of permanent pastures and 19% of forest and woodland in the region were estimated to be affected by some form of degradation in 1990 (Oldeman, 1994; WRI, 2005).

There is considerable variance among countries in SSA as to estimates of the costs of losses resulting from land degradation. In a 12-country study, the gross discounted cumulative loss (a metric which takes into account the cumulative nature of land degradation) varied from less than 1 to 44% of GDP with, for the most part, modest annual productivity losses (1-3%) (Bojo, 1996).

Desertification occurs when land degradation processes affect dry lands and is the most widespread form of land degradation in the region, affecting about 46% of Africa (Reich et al., 2001). A recent examination of existing available data however does not support the claim that the African Sahel is a desertification hotspot (Lepers et al., 2005), and in fact net greening has been observed following the droughts of the early 1980s. Possible reasons for this include changes in rainfall patterns, land use changes and improved land management (Olsson et al., 2005).

Insufficient nutrient replacement in agricultural systems on land with poor to moderate potential results in soil degradation. Whereas soil moisture stress inherently constrains land productivity on 85% of soils in Africa (Eswaran et al., 1997), soil fertility degradation now places an additional serious human-induced limitation on productivity (Figure 1-2).

Approximately 25% of soils in Africa are acidic, and therefore deficient in phosphorus, calcium and magnesium with often toxic levels of aluminum (McCann, 2005). Use of fertilizer in the region is the lowest in the world with average applications of less than 9 kg of nitrogen and 6 kg of phosphorus per ha, compared with typical crop requirements of 60 kg of nitrogen and 30 kg of phosphorus per ha. Recent research estimates that every country in SSA had a negative soil nutrient balance; the amount of nitrogen, phosphorus and potassium added as inputs was significantly less than the amount removed as harvest or lost by erosion and leaching (Swift and Shepherd, 2007). Although many farmers have developed soil management strategies to cope with the poor quality of their soil, low inputs of nutrients, including organic matter, contribute to poor crop growth and the depletion of soil nutrients.

1.2.1.2 Water

Freshwater resources are a critical input for agriculture, fisheries and livestock production as well as many other economic activities. SSA has significant surface and groundwater resources but they are unevenly distributed (FAO, 2002). The region is home to six of the world's major river basins, namely the Congo, the Nile, the Niger, Lake Chad, Zambezi and Orange Rivers, and includes large water bodies such as Lakes Victoria, Tanganyika and Nyasa (UNEP, 2002b). Actual renewable freshwater resources average 6,322 m^3 per capita, but this varies widely from only 509 m^3 per capita in Burundi to about 218,000 m^3 per capita in the Congo (D.R. Congo data not available) (WRI, 2005).

The agricultural sector is by far the biggest user of water resources; 88% of the total annual water withdrawals in SSA in 2000 were from agriculture, 4% by industry and 9% for domestic use (WRI, 2005). With growing demand for water resources from all sectors, it is projected that by 2025, 13 countries in SSA will experience water stress (less than 1,700 m^3 per capita per year) and another ten countries will suffer from water scarcity (less than 1,000 m^3 per capita per year) (UNEP, 2002b).

Furthermore, degradation of water resources including watersheds, wetlands and groundwater is occurring. For example, soil erosion leading to siltation of rivers and lakes adversely affects people's health and access to clean water, and biodiversity, including fisheries, by changing the ecological conditions under which species live (MA, 2005a).

1.2.1.3 Biodiversity

Sub-Saharan Africa is rich in both a variety and abundance of biological diversity. The region closely corresponds to the Afrotropical biogeographical realm, which is the second most abundant realm in terms of numbers of species and endemic species (amphibians, birds, mammals and reptiles) after the Neotropical realm (Latin America and the Caribbean) (MA, 2005ab). Sub-Saharan Africa has a range of major habitat types or biomes, dominated by tropical and sub-tropical grasslands, savannas and shrub-lands. Other major habitat types include tropical and sub-tropical moist broadleaf forests, and deserts and xeric shrub-lands (MA, 2005c). These biomes have the highest levels of overall species richness (MA, 2005b). The region contains five internationally recognized "biodiversity hot spots" or areas of species richness and endemism which are under particular threat, namely the Western Indian Ocean islands, particularly Madagascar, the Cape Floristic Kingdom and the Succulent Karoo, both in southern Africa, the Guinea Forest in western Africa, and the Eastern Arc Mountain Forests of eastern Africa (UNEP, 2002a).

Plant and animal biodiversity are central to human well-being, most notably in food production but also as a source of fiber for clothing, wood for implements, shelter, and fuel, and for natural medicines and products, as well as having strong cultural and spiritual significance. Agricultural biodiversity encompasses domesticated crop plants and animals used for livestock or aquaculture, as well as wild food sources, their wild crop relatives, and "associated" biodiversity that supports agricultural production through nutrient recycling, pest control and pollination (Wood and Lenne, 1999). A number of important agricultural crops originated in Africa including several species of millet and sorghum, the oil palm and coffee (UNEP, 2006a). The Afrotropic terrestrial realm is among the most productive in terms of net primary productivity and biomass values (MA, 2005b), suggesting that agricultural output in this region could also be highly productive under suitable conditions.

Principal threats to biodiversity in Africa include land use and land cover change, mainly through conversion of natural ecosystems, particularly forests and grasslands, to agricultural land and urban areas. It is likely that land clearing and deforestation will continue and hence threaten genetic diversity as species loss occurs.

Only about 6% of sub-Saharan Africa, or 142 million ha, falls under protected areas (WRI, 2005), with the best protected being the savannah habitats of eastern and southern Africa, while the least protected are found in Madagascar, the drier parts of South Africa, and the most heavily deforested parts of West and East Africa (Figure 1-3). Plants are also less well covered by the network of protected areas than charismatic animals, such as large mammals (UNEP, 2006a).

1.2.1.4 Forests

About 19% of the land area of SSA is classified as forest (defined as more than 10% tree cover) although estimates range between 18-52% depending on the percentage tree covers (WRI, 2005). The percentage of an individual country covered by forests ranges from a high of 85% in Gabon to a low of 0.5% in Lesotho (FAO, 2007a). The greatest extent of forest cover is found in Central Africa—the Congo basin covers 200 million ha and is the world's second largest continuous tropical rain forest after the Amazon (Bruinsma, 2003). Other significant areas include the Guinea Forest of West Africa, the Eastern Arc Mountain Forests of East Africa, the Mopane and Miombo woodlands of southern Africa and in eastern Madagascar.

Forests and woodlands are facing increasing pressures from a growing human population including encroachment and conversion for agricultural expansion, illegal logging and poaching of wild animals, overgrazing leading to loss of woody vegetation, and the impacts of conflicts. One of the prominent forest cover changes in sub-Saharan Africa has been in the sub-tropical dry Miombo forests in southern Africa (Lepers et al., 2005).

Forests provide a number of important ecosystem services: provisioning services such as supplying timber and non-timber forest products including wild foods, medicines, pharmaceuticals and genetic resources; regulating services such as flood and climate regulation; cultural services including spiritual, aesthetic, as well as recreational values; and supporting services including primary production, nutrient cycling and soil formation. The large majority of households in sub-Saharan Africa, rural and urban, still depend on biomass in the form of wood or charcoal for their energy needs and many also depend on wood and fiber for their shelter and household items, and for income generation (see SSA Chapter 2).

1.2.1.5 Climate

Climate variability is the single most important atmospheric phenomena in sub-Saharan Africa. The region experiences a high degree of variability and uncertainty in climatic conditions, with associated droughts and floods, which occur regularly (UNEP, 2002a). A recent analysis of long-term trends (1900 to 2005) indicates rising temperatures in Africa as a whole, as well as drying, or decreased precipitation, in the Sahel and southern Africa (IPCC, 2007a). In addition, the El Nino Southern Oscillation (ENSO) causes significant climatic disturbances in many parts of the continent, either inducing drought or flooding, or increasing sea temperatures, which lead to cyclones, particularly over the Indian Ocean. Overall, longer and more intense droughts have been observed since the 1970s, particularly in the tropics and subtropics (IPCC, 2007a).

Generally the continent suffers from relatively little atmospheric pollution, except in major cities where emissions from industry, motor vehicles and household use of biomass for energy are rising (UNEP, 2006a). Nevertheless, sub-Saharan Africa is the most vulnerable region to the impacts of climate change (IPCC, 2007b) and yet it contributes the least in terms of greenhouse gas (GHG) emissions such as carbon dioxide, the principal GHG responsible for global warming. The region only contributes about 2-3% of global CO_2 emissions from energy and industrial sources. On average 0.8 tonnes per capita were released in 2000 compared with a global per capita average of 3.9 tonnes (12.4 tonnes per capita in high income countries and 19.8 tonnes per capita in the United States, the world's highest emitter) (UN, 2006; World Bank, 2006). In other words, an inhabitant of the USA emits about 24 times as much CO_2 as an inhabitant of sub-Saharan Africa.

There is now unequivocal evidence that the climate system is warming, and that this is very likely a result of observed increases in anthropogenic GHG levels. These increases result primarily from agriculture—both from inputs such as fossil fuels, and land-use changes associated with agricultural practices (IPCC, 2007a). Climate data for Africa for the last 30 to 40 years shows that if the current trends continue, by 2050, SSA will be warmer by 0.5 to 2 C°, and drier, with 10% less rainfall and water loss exacerbated by higher evaporation (Nyong, 2005). Sub-Saharan Africa is vulnerable to climate change and global warming because of widespread poverty and limited adaptive capacity (IPCC, 2007b). The impact of these climatic changes are already manifesting in SSA as evidenced by the loss of 82% of ice mass on Kilimanjaro mountain, 40-60% decrease in available water in Niger, Senegal, and Lake Chad during the last two centuries (CBD, 2007). The impacts of climate change are likely to be manifest at various spatial and temporal scales. These include sea level rise and flooding of low-lying coastal and estuarine areas (among the most densely populated). Climate change will particularly affect small islands such as those of the western Indian Ocean (e.g., Seychelles, Comoros and Mauritius) as well as mangrove forests, with consequences for coastal fisheries.

Changes in rainfall and temperature patterns are likely to negatively affect water availability and growing conditions, reducing food production and security, as well as hydroelectricity production. Biodiversity and ecosystems, including agroecosystems, are likely to be severely affected as many species may not be able to adapt or migrate to more suitable areas. The intensity of tropical cyclones is also

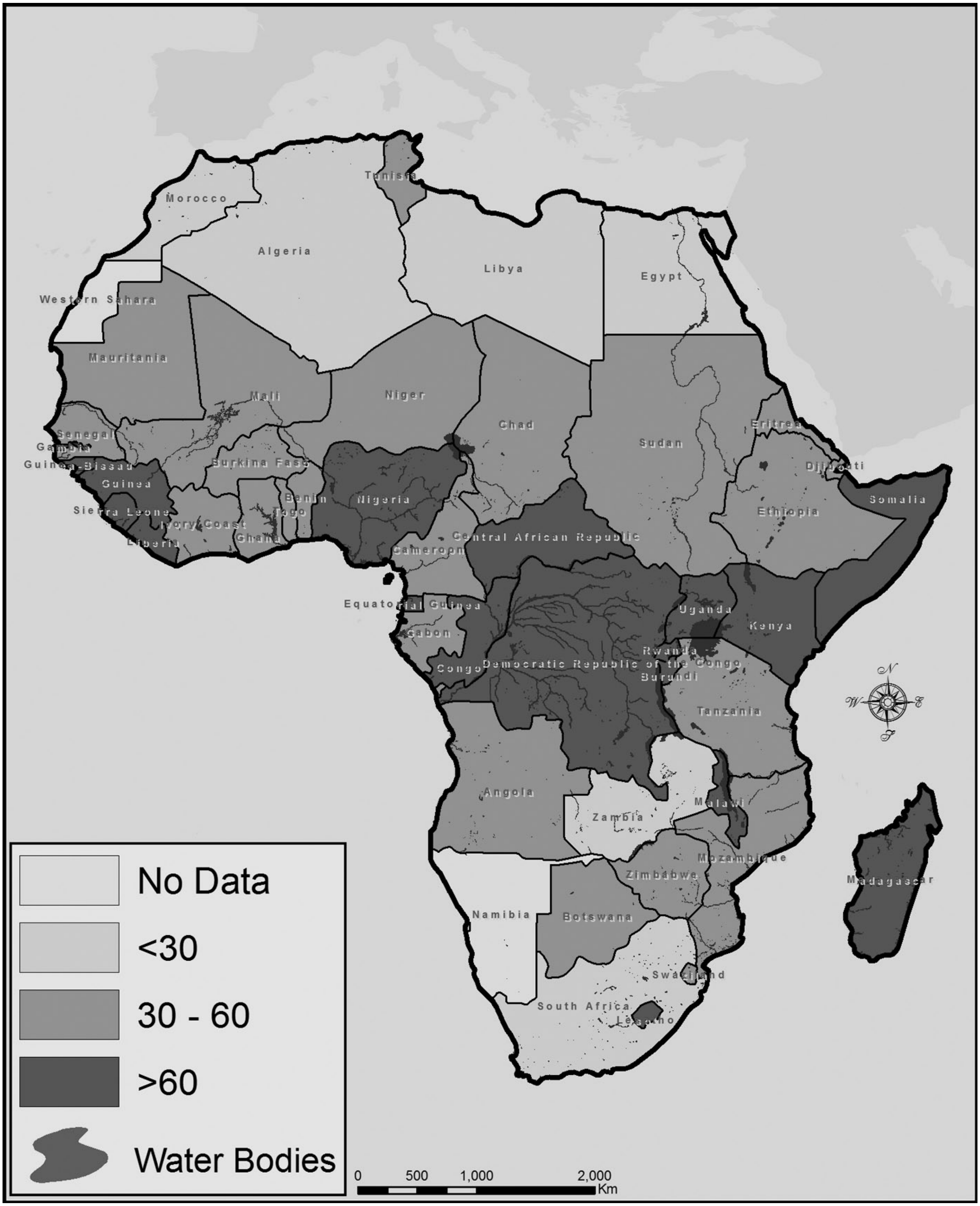


Figure 1-2. *Net annual rates of macronutrient (NPK) depletion for Africa. Source: Henao and Baanante, 2006.*

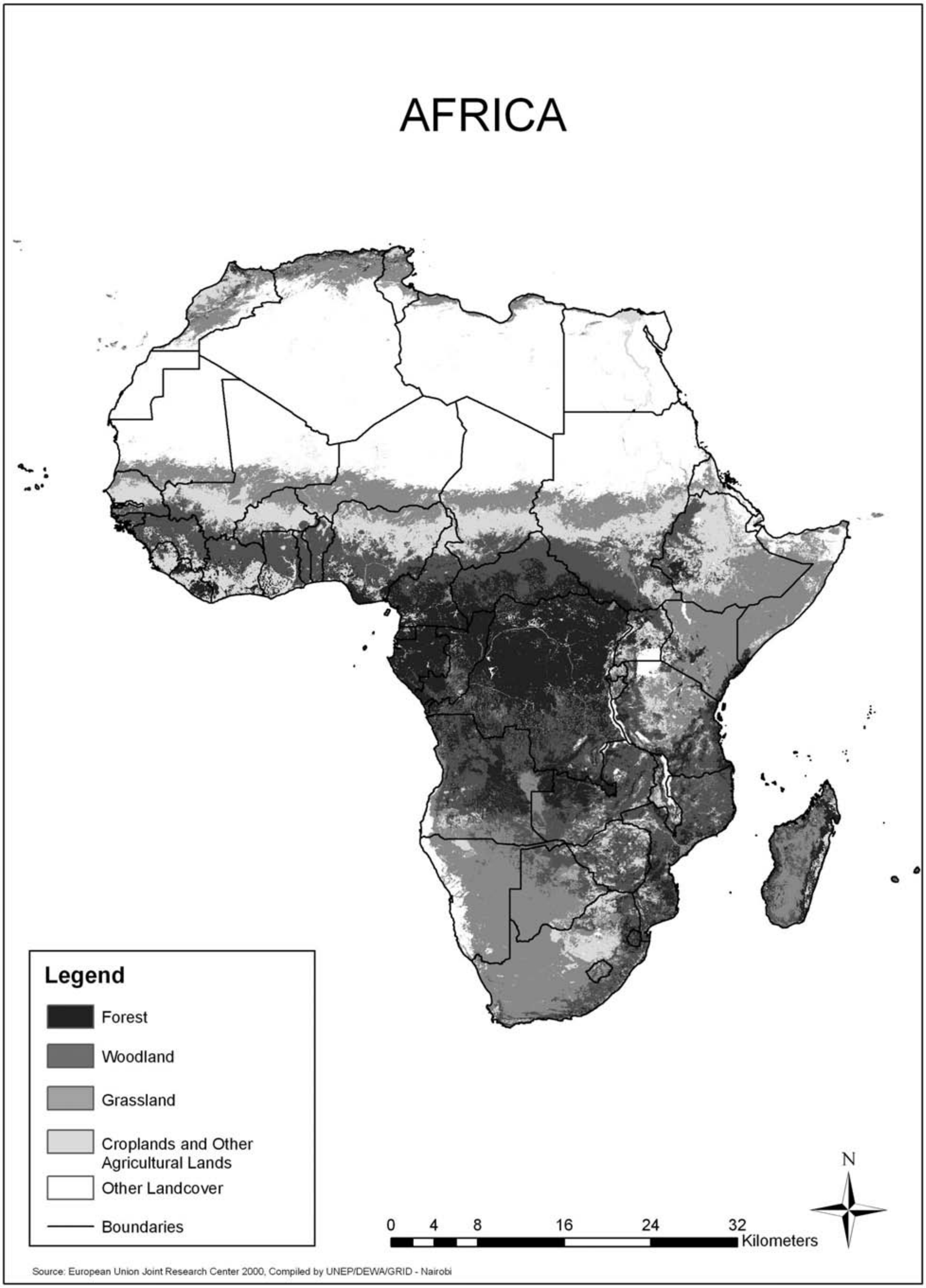


Figure 1-3. *Africa's land cover. Source: ECJRC, 2003; UNEP/DEWA/GRID, 2005.*

likely to increase, and the cyclone zone may expand, making the western Indian Ocean islands even more vulnerable than they already are. Patterns of disease distribution are also likely to change (IPCC, 2007b; UNEP, 2002b). Although global efforts to address the causes of climate change are underway, global warming and sea level rise are likely to continue for centuries to come because of the timescales associated with climate processes and feedbacks

Countries in SSA have a wide diversity of farming systems. Farming systems in SSA can be identified by the following four types (IAC, 2004):

- The maize-mixed system, which is based primarily on maize, cotton, cattle and goats.
- Cereal/root crop-mixed system, which is based on maize, sorghum, millet, cassava, yams and cattle.
- Irrigated system, based on maize, sorghum, millet, cassava yams and cattle.
- The tree crop-based system, anchored in cocoa, coffee, oil palm and rubber, mixed with yams and maize.

Subsistence farming dominates the farming system in SSA. There is little application of technology, particularly with food crops, leading to low agricultural productivity. Cash crops tend to be better developed than food crops (IAC, 2004). Farm sizes tend to be small and decline over time (Ellis, 2005; Nagayets, 2005). Average farm size in four SSA countries (Kenya, Uganda, Tanzania and Malawi) was about 1.55 ha (Ellis, 2005). Generally, the average size of land holdings declined from 1.5 hectares in 1970 to 0.5 hectares in 1990 (Nagayats, 2005). The decline of farm size partially reflects the exhaustion of land frontiers in most SSA countries. It is important therefore to take into account the peculiar needs and concerns of farmers engaged in these various farming systems when developing agricultural technologies or during extension delivery.

1.2.2 Social, economic, cultural and political characteristics

Sub-Saharan Africa is a region that is often divided for different types of analysis based on social, economic, cultural, political and historical sub-regional characteristics. For a more productive division for discussion of AKST, SSA is considered as comprised of six distinct regions: East Africa, Sudano-Sahel, West Africa, the Central Africa, Southern Africa and the Islands of the Indian Ocean (Lelo and Makenzi, 2000; Table 1-2). About one-half of the countries comprising SSA are Anglophone and one-half are Francophone. The colonial legacy influences considerations of economic integration and joint development activities, including agricultural development. This fragmentation presents a roadblock to regional synergy and economies of scale.

Present day boundaries of SSA countries are a legacy of colonialism (Britannica, 2007). The European insistence on drawing borders around territories to isolate them from those of other colonial powers often had the effect of separating otherwise contiguous political groups, or forcing traditional enemies to live side by side with no buffer between them. These changes introduced cultural dichotomies detrimental to the native inhabitants. For example, although the Congo River appears to be a natural geographic boundary, there are groups that otherwise share common language and culture on both sides of the river. However, the division of the land between Belgium and France created boundaries that isolated groups with similar cultures.

Table 1-2. *IAASTD sub-Saharan Africa (SSA) countries and regions.*

Central Africa	West Africa	East Africa
Burundi	Benin	Ethiopia
Cameroon	Cape Verde	Eritrea
Central African Republic	Cote d'Ivoire	Kenya
Democratic Rep. Congo	Gambia, The	Tanzania
Equatorial Guinea	Ghana	Uganda
Gabon	Guinea	
Republic of Congo	Guinea-Bissau	**Southern Africa**
Rwanda	Liberia	Angola
	Sierra Leone	Botswana
	Togo	Lesotho
Sudano-Sahel	Sao Tome and Principe	Malawi
Burkina Faso		Mozambique
Chad	**Indian Ocean Islands**	Namibia
Mali	Comoros	South Africa
Niger	Madagascar	Swaziland
Nigeria	Mauritius	Zambia
Senegal	Seychelles	Zimbabwe

Note: Some of the data used differ in definition of SSA, but differences are marginal for purposes of this assessment.

Sub-Saharan Africa has the world's fastest growing populations, estimated at 2.7% a year, compared to 2% and 2.2% a year in Asia and Latin America respectively (Haggblade et. al, 2004). At the same time the per capita food production index shows a decline from 1.0 in 1961 to 0.82 in 2002 while the index in Asia and Latin America increased from 1.0 in 1961 to 1.82 and 1.25 respectively (Haggblade et. al, 2004). The population is unevenly distributed with semi-arid areas not as densely populated as some of more fertile areas (Lelo and Makenzi, 2000). The country with the largest population is Nigeria with 136.5 million. It is followed by Ethiopia with 68.6 million and the Democratic Republic of Congo with 53.2 million.

In sub-Saharan Africa women play a central role in agricultural production (growing about 80% of staple food crops), yet most of their contribution goes unrecognized. They are also critical to household well-being, with the majority of rural and low-income urban women performing up to 50 hours per week of domestic tasks, including caring for children, and performing essential social functions within their communities. All of these responsibilities are borne by women and yet males are the primary household decision makers and in many countries boys are still the recipients of most educational opportunities (Manuh, 1998; Bruinsma, 2003; Harsch, 2004). In addition, women have been among those most affected in SSA by HIV/AIDS, structural adjustment programs and civil strife and conflict. The majority of refugees are women and children (Manuh, 1998).

The economies of SSA are diverse and shaped by international trade relations. Currently, SSA and the rest of African countries, Caribbean and Pacific countries are faced with critical negotiations with the European Union concerning the establishment of Economic Partnership Agreements.

Further diversity is exhibited in languages: SSA is the most diverse in the world with over two thousand different indigenous languages (Kim and Kim, 2003). Most farmers in the rural areas use these indigenous languages while extension agents rely more on exogenous ones such as English and French. This reliance limits the effectiveness of extension communication

1.2.3 Hunger, nutrition and human health

Progress has been made against hunger globally, but the slow growth of agricultural outputs and expanding population has led to setbacks in regions like SSA (IAC, 2004). Hunger tends to be concentrated among the landless or among farmers whose plots are too small to provide for their needs.

About 33% and 31% of people in sub-Saharan Africa were undernourished during 1990-92 and 2001-2003 respectively (FAO, 2007b) with 32% of children under five years of age characterized as underweight (FAO, 2002). The status of undernourishment is varied among SSA countries. For example, more than 60% of the undernourished population is in East Africa. More than half of the populations in the Democratic Republic of Congo and Mozambique are classified as undernourished, while Angola, Cameroon, Ethiopia, Kenya, Tanzania, and Zambia show prevalence rates between 40 and 50% (FAO, 2002). However, the absolute number of undernourished people increased from 172 millions in 1990-92 to 209 million in 2001-2003 (FAO, 2007b). This means that the reduction in undernourishment has not kept pace with the population growth rate. The social and economic consequences of malnutrition are widely felt, not only in the health sector but also in education, industry, agriculture, transport, human resources and the economy in general.

In the last decade, 14 countries in SSA have managed to reduce hunger by 25%. These countries had better economies and investment in interlinked socioeconomic policy (UNECA, 2005). However, the majority of countries in SSA do not meet the World Health Organisation (WHO) standard of at least 20 physicians per 100,000 people (World Bank, 2006).

An estimated 24.5 million people were living with HIV at the end of 2005 and approximately 2.7 million new infections occurred during that year. HIV/AIDS is adversely affecting the population structure of some parts of sub-Saharan African countries as the vast majority of people living with HIV and AIDS in Africa are between the ages of 15 and 49 and more than 12 million children are now orphans because of AIDS (Deame, 2001). However, the number of adults (over age 15) living with HIV and AIDS varies greatly among SSA countries (AVERT, 2007). For example, in Senegal the prevalence is under 1% of the population, whereas in South Africa and Zambia around 17-19% of that age group is infected. Rates exceeding 20% are recorded in Botswana (24.1%), Lesotho (23.2%), Swaziland (33.4%) and Zimbabwe (20.1%). West Africa has been less affected by HIV, but the prevalence rates in some countries are increasing. Prevalence is estimated to exceed 5% in Cameroon (5.4%), Côte d'Ivoire (7.1%) and Gabon (7.9%).

The experience of Uganda shows that HIV prevalence can fall; by 2001 HIV prevalence was around 5%, down from around 15% in the early 1990s. This change is thought to be largely due to intensive HIV prevention campaigns. More recently, similar declines have been seen in Kenya, Zimbabwe and urban areas of Zambia and Burkina Faso (AVERT, 2007).

HIV and AIDS prevalence in SSA is having a heavy toll on the availability of productive labor. Appropriate agricultural technologies do not necessarily imply labor intensive technologies (UNECA, 2005) and should correspond to the available labor force of a given area. Another related problem, given the high food insecurity in SSA, is the improvement of nutrition for HIV-infected people to reduce their chances of developing AIDS.

Malaria also contributes to the health challenges in SSA. It is estimated that 90% of the people who die from malaria are in SSA (World Bank, 2006). HIV and AIDS, malaria and other health factors result in premature deaths that disrupt the transmission of agricultural knowledge from one generation to the next, and reduce the labor force.

1.2.4 Poverty, livelihoods and the economy

The rate of economic growth in SSA has improved in the last 10-15 years (McKinley, 2005), but has remained low and in last few decades has had the worst growth performance of any region in the world (Garner, 2006; World Bank, 2006). Poor performance has been attributed to low investment, inappropriate policies and institutions and geographical constraints.

Between 1996-2005 (World Bank, 2006), fifteen SSA countries (Mozambique, Rwanda, Cape Verde, Uganda, Mali, Botswana, Ethiopia, Tanzania, Mauritania, Benin, Ghana, Senegal, Burkina Faso, Gambia and Cameroon) recorded annual growth rates of more than 4.5%. During the same period, thirteen SSA countries recorded growth rates of only 1.3% (Swaziland, Kenya, Lesotho, Eritrea, Comoros, Seychelles, Cote d'Ivoire, Burundi, Sierra Leone, central African republic, Guinea-Bissau, DRC Congo, and Zimbabwe) (World Bank, 2006).

Between 1998-2000, agricultural GDP averaged 29% of the total GDP and agricultural labor comprised 66.6% of the total labor force in SSA (Beintema and Stads, 2004). Rural livelihoods in SSA are diversified between farm and non-farm activities but are largely dependent on agriculture, either directly or indirectly as agriculture is both a source of income and means to food security (Pinstrup-Andersen and Cohen, 2001).

Agricultural research directly contributes to growth and development (IAC, 2004); stimulating agricultural growth in SSA can contribute significantly to economic growth and poverty reduction. By increasing food availability and incomes and contributing to asset diversity and economic growth, higher agricultural productivity and supportive pro-poor policies allow people to break out of the poverty-hunger-malnutrition trap (Garner, 2006). Improving the productivity and the economic returns of agriculture can have immediate effects on poverty and hunger (Kydd, 2002).

A nation's ability to solve problems and initiate and sustain economic growth depends partly on its capabilities in science, technology, and innovations (UN Millennium project, 2005). Scientific, technological, and innovation capacity are often associated with economic growth (IAC, 2004). SSA and South Asia have the lowest access to information and communication technologies (Pigato, 2001).

Poverty reduction requires a combination of economic growth and a reduction in inequality (Okojie and Shimeles, 2006). Recent studies have shown that both income and non-income inequalities are high in sub-Saharan Africa (Okojie and Shimeles, 2006; World Bank, 2006; Blackden et al., 2006) with the level of inequality lower in rural areas (Okojie and Shimeles, 2006; Table 1-3) Countries with high initial income inequality find economic growth to be less effective in reducing poverty (Okojie and Shimeles, 2006). For example, in Tanzania the pace of poverty reduction would have been substantial had it not been for the dampening effects of a rise in inequality in the wake of economic growth (Demombynes and Hoogeveen, 2004).

Gender inequalities also play a significant role in accounting for SSA's poor growth and poverty reduction performance (Townsend, 1999; Blackden et al., 2006). Analysis from Kenya suggests that giving women farmers the same education and inputs as men increases yields by as much as 22 percent. For Burkina Faso, analysis of household panel data suggests that farm output could be increased 6-20% through a more equitable allocation of productive resources between male and female farmers (World Bank, 2001).

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 (IAC, 2004). 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 poor, rural Africans still depend heavily on agriculture for their livelihoods, many also have diversified into non-farm income sources, including 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 labor. On the other hand, more diversified households may have more capital of their own to invest in new agricultural technologies and resource improvements and be better able to withstand shocks and risks.

Smallholders dominate the agricultural sector and have shown a capability of adopting new technology options where the right incentives and market opportunities exist (IAC, 2004). Each 10% increase in smallholder agricultural productivity in SSA can move almost 7 million people above the dollar-a-day poverty line (IFPRI, 2006). 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 (IAC, 2004).

1.2.5 Agricultural R&D investments

Despite the evidence of high returns from agricultural research and its importance for agricultural development, growth in agricultural research and development (R&D) investments has stagnated in sub-Saharan Africa. In addition, due to political, social, and economic unrest as well as institutional changes (mergers, subdivisions, relocation, reshuffling and so on), research systems have experienced greater instability than those in other regions in the world. As a result public agricultural research spending has fluctuated in many countries (Beintema and Stads, 2006).

Most of the growth in sub-Saharan African agricultural R&D spending took place in the 1960s when real (inflation-adjusted) investments in agricultural R&D increased by an average of 6.3% per year. Annual growth declined from 1.3% during the 1980s to only 0.8% in during the 1990s

Table 1-3. *Measures of inequality for Africa relative to other world regions in the 1990s.*

Inequality indicators	Average	Standard deviation	Maximum	Minimum	East Asia & Pacific	South Asia	Latin America	Industrial countries
Gini Coefficient	44.4	8.9	58.4	32.0	38.1	31.9	49.3	33.8
Share of top 20%	50.6	7.4	63.3	41.1	44.3	39.9	52.9	39.8
Share of middle class	34.4	4.3	38.8	38.8	37.5	38.4	33.8	41.8
Share of bottom 20%	5.2	5.2	8.7	2.1	6.8	8.8	4.5	6.3

Source: UNECA, 1999.

Table 1-4. *Total public agricultural research expenditures in sub-Saharan Africa.*

	Agricultural R&D spending[a]			Annual growth rates[b]		
	1981	1991	2000	1981-1991	1991-2000	1981-2000
	(million international dollars, year 2000)			(percentage)		
Public sector						
Kenya	65	106	130	5.0	0.6	4.5
Nigeria	144	77	117	-6.7	4.7	-2.4
South Africa	296	309	360	0.1	1.9	1.5
Subtotal	1,196	1,365	1,461	1.3	0.8	1.0
Private sector	n/a	n/a	26	n/a	n/a	n/a
Total	**n/a**	**n/a**	**1,486**	**n/a**	**n/a**	**n/a**

Note: The total includes 44 sub-Saharan African countries. Kenya, Nigeria, and South Africa were the only countries that spent over $100 million (2000 international dollars) in 2000. The research capacity of 17 countries was estimated in line with their share of total agricultural output.

[a]Spending data are expressed in international financial data and were converted to 2000 international dollars by deflating current local currency units with local GDP deflator (base year 2000) and then converted to international dollars using a 2000 purchasing power parity (PPP) index. PPP's are synthetic exchange rates used to reflect the purchasing power of currencies, typically comparing prices among a broader range of goods and services than conventional exchange rates.

[b]Annual growth rates are calculated using the least-squares regression method, which takes into account all observations in a period. This results in growth rates that reflect general trends that are not disproportionately influenced by exceptional values, especially at the end point of the period.

Source: Beintema and Stads, 2006; Pardey et al., 2006.

(Table 1-4). As a result sub-Saharan Africa's share in total spending on agricultural R&D worldwide declined from 8% in 1981 to 6% two decades later. This is a contrasting trend with that of other regions in the developing world that experienced an increase in their global shares. In 2000, sub-Saharan Africa's public agricultural R&D spending totaled $1.5 billion (in 2000 international dollars). The three largest systems, in terms of expenditures, accounted for more than 40% of the regional total.

The role of the private sector in R&D in SSA is still small and many of the private-sector activities focus solely on the provision of input technologies or technological services for agricultural production, with most of these technologies being produced in industrialized countries. In 2000, private firms in sub-Saharan Africa invested $26 million in agricultural R&D, representing only 2% of total public and private research investments; almost two thirds of the private-sector investment was done in South Africa.

The regional averages on agricultural R&D spending mask considerable differences among the 27 sub-Saharan countries for which time series data were available (Table 1-5). More than half of these sample countries spent less on public agricultural R&D in 2000 than 10 years earlier. Growth rates in Burundi, the Republic of Congo, and Sudan were below negative 10%, for example. Declines were the result of the completion of large donor-funded projects (Burkina Faso, Guinea, Madagascar, Niger, Togo, and Zambia) or political unrest (Burundi and Sudan).

Agricultural research in sub-Saharan Africa became increasingly dependent on donor funding toward 2000; but it appears that the share of donor contributions in total funding declined in the later half of the 1990s—at least for the 23 countries for which detailed data were available. These declines resulted in part from the completion of a large number of World Bank projects in support of agricultural R&D or the agricultural sector at large. Donor contributions (including World Bank loans) accounted for an average of 35% of funding to principal agricultural research agencies in 2000. These regional averages mask great variation among countries. In 2000, donor funding accounted for more than half of the agricultural R&D funding in 7 of the 23 countries. Eritrea, in particular, was highly dependent on donor contributions. Its principal agricultural research agency received more than three-quarters of its funding from donors. In contrast, donor funding was virtually insignificant in Botswana, Malawi, Mauritius, and Sudan (under 5%). Funding through sources other than government or donors, such as internally generated revenues, was relatively small, representing 11% of total funding in 2000 (Beintema and Stads, 2006).

Table 1-5. *Variation in annual growth rates in total spending in 27 sub-Saharan African countries, 1991-2000.*

Positive		Stagnating		Negative	
		(%)			
South Africa	1.8	Benin	-0.7	Burundi	-16.2
Mauritania	3.7	Kenya	0.6	Congo	-12.7
Gabon	4.1	Mali	1.1	Sudan	-11.0
Botswana	5.6	Ghana	1.1	Niger	-8.4
Mauritius	6.2			Madagascar	-7.9
Nigeria	6.3			Zambia	-7.3
Ethiopia	7.1			Gambia	-7.1
				Malawi	-5.5
				Togo	-4.4
				Côte d'Ivoire	-3.4
				Burkina Faso	-3.2
				Senegal	-3.1
				Guinea	-2.8

Note: Stagnating countries have annual growth rates between -1.5 and 1.5%.

Annual growth rates are calculated using the least-squares regression method.

Source: Beintema and Stads, 2006.

References

AVERT. 2007. Sub-Saharan HIV and AIDS statistics. Available at http://www.avert.org/subaadults.htm. AVERT, Sussex.

Beintema, N., and G.-J. Stads. 2004. Sub-Saharan African agricultural research: Recent investment trends. Outlook Agric. 33:239-246.

Beintema, N., and G.-J. Stads. 2006. Agricultural R&D investments in sub-Saharan Africa: An era of stagnation. IFPRI, Washington DC.

Blackden, M., C. Canagarajah, S. Klasen, and D. Lawson. 2006. Gender and growth in sub-Saharan Africa: Issues and evidence. Available at http://www.wider.unu.edu/publications/working-papers/research-papers/2006/en_GB/rp2006-37/. World Inst. Dev. Econ. Res, Helsinki.

Bojo, J. 1996. The costs of land degradation in sub-Saharan Africa. Ecol. Econ. 16:161-173.

Britannica. 2007. Africa, the colonial legacy. Available at http://www.britannica.com/ebi/article-195882. Britannica Student Encyclopedia Online.

Bruinsma, J. (ed) 2003. World agriculture towards 2015/2030: An FAO perspective. Earthscan, London.

CBD. 2007. International day for biological diversity. Available at http://www.cbd .int/programmes/outreach/awareness/biodiv-day-2007.shtml. Convention on Biodiversity, Montreal.

Deame, L. 2001. Earth trends: Global AIDS toll bleak. Available at http://www .earthtrends.wri.org/features/view_feature .php?theme=4&fid=21. World Resources Inst., Washington DC.

Demombynes, G., and J. Hoogeveen. 2004. Growth, inequality and simulated poverty paths for Tanzania, 1992-2002. Policy Res. Working Pap. 3432. World Bank, Washington DC.

ECJRC. 2003. Global land cover 2000. Available at http://ies.jrc.cec.eu.int/31.html. European Commission Joint Res. Center, Brussels.

Ellis, F. 2005. Small farms, livelihood diversification, and rural-urban transitions: Strategic issues in Sub-Saharan Africa. Available at http://www.ifpri.org/events/seminars/2005/smallfarms/sfproc/SO4_Ellis .pdf. School Dev. Studies, Univ. East Anglia, UK.

Eswaran, H., R. Alcatraz, E. van den Berg, and P. Reich. 1997. An assessment of the soil resources of Africa in relation to productivity. Geoderma 77:1-18.

FAO. 2002. Comprehensive Africa agriculture development programme: New partnership for Africa's development. FAO, Rome.

FAO. 2007a. FAO statistical databases [Online]. Available at http://www.faostat .fao.org. FAO, Rome.

FAO. 2007b. Report on food deprivation: Towards the Millennium Development Goals on hunger reduction. Stat. Div. Working Pap. Ser. ESS/ESSA/008e. FAO, Rome.

Garner, P. 2006. Economic growth in sub-Saharan Africa. Available at http://ssrn .com/abstract=853184. Social Sci. Res. Network.

Haggblade, S., I. Kirsten, R. Mkandawire, and F.P. de Vries. 2004. Agricultural successes in the Greater Horn of Africa: Conference overview. NEPAD/IGAD Conf. Agricultural successes in the Greater Horn of Africa. Nairobi, 22-25 Nov 2004. NEPAD, Johannesburg.

Harsch, E. 2004. Agriculture: Africa's engine for growth. Africa Recovery 17(4):13.

Henao, J., and C.A. Baanante. 2006. Agricultural production and soil nutrient mining in Africa: Summary of IFDC technical bulletin. IFDC, Muscle Shoals AL.

IAC. 2004. Realizing the promise and potential of African agriculture: Science and technology strategies for improving agricultural productivity in Africa. InterAcademy Council, Amsterdam.

IFPRI. 2006. The role of agriculture development: Implications for sub-Saharan Africa. Disc. Pap. 29. IFPRI, Washington DC.

ILO. 2005. Global employment trends model. Available at http://www.ilo.org/public/english/employment/strat/global06.htm. Int. Labor Office, Geneva.

IPCC. 2007a. Climate change 2007: The physical science basis: Summary for policy makers. Contribution of working group 1 to the Fourth Assessment Report of IPCC. Cambridge Univ. Press, UK.

IPCC. 2007b. Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group 2 to the Fourth Assessment Report of IPCC. Cambridge Univ. Press, UK.

Kim, H., and J. Kim. 2003. Diversity, institutions and economic growth in Sub-Saharan Africa. 1st KIEP Africa Regional Seminar, Korean Inst. Econ. Policy, 27 Feb 2003. Available at http://www.keusa .or.kr/europe/Document/2003-2/2003-2-5 .pdf.

Kydd J., A. Dorward , J. Morrison, and G. Cadisch. 2002. Agricultural development and pro poor economic growth in sub-Saharan Africa: Potential and policy. Available at http://ageconsearch.umn.edu/bitstream/123456789/25394/1/adwp0204 .pdf. ADU Working Pap. 02/04. Imperial Coll. Sci. Tech. Med., Wye.

Lelo, K.F., and P.M. Makenzi. 2000. Sustainable use and development in sub-Saharan Africa: Proc. 2nd Pan-African Symp. Sustainable use of natural resources in Africa, Ouagadougou. July 2000. Available at http://www.iucn.org/themes/ssc/susg/resources/pas2.htm. IUCN, Gland.

Lepers, E., E.F. Lambin, A.C. Janetos, R. DeFries, F. Achard, N. Ramankutty, and R.J. Scholes. 2005. A synthesis of information on rapid land-cover change for the period 1981-2000. Available at http://www.geo.ucl.ac.be/LUCC/lucc.html.

Manuh, T. 1998. Women in Africa's development: Africa recovery. Briefing Pap. 11. Available at http://www.un.org/ecosocdev/geninfo/afrec/bpaper/maineng .htm. UN, Geneva.

MA. 2005a. Cultivated systems: Current state and trends assessment. Millennium Ecosystem Assessment, Island Press, Washington DC.

MA. 2005b. Biodiversity: Current state and trends assessment. Island Press, Washington, DC.

MA. 2005c. Ecosystems and human well-being: Biodiversity synthesis. Millennium Ecosystem Assessment, Island Press, Washington DC.

McCann, J.C. 2005. Maize and grace: Africa's encounter with a new world crop 1500-2000. Harvard Univ. Press, Cambridge.

McKinley, T. 2005. Economic alternatives for sub-Saharan Africa: Poverty traps, MDG-based strategies and accelerated capital accumulation: Paper for the G-24 Meeting, 15-16 Sept 2005. Available at http://www.g24.org/mcki0905.pdf. UNDP, New York.

Nagayets, O. 2005. Small farms: Current status and key trends: Information brief prepared for the Future of Small Farms Research Workshop, Wye College, 26-29 June 2005. Available at http://www.ifpri.org/events/seminars/2005/smallfarms/sfproc/Appendix_InformationBrief.pdf.

Nyong, A. 2005. Impacts of climate change in the tropics: The African experience. Available at http://www.stabilisation2005 .com/Tony_Nyong.pdf. Univ. Jos, Nigeria.

Okojie, C., and A. Shimeles. 2006. Inequality in sub-Saharan Africa: A synthesis of recent research on the levels, trends, effects and determinants of inequality in its different dimensions. Overseas Dev. Inst., London.

Oldeman, L.R. 1994. The global extent of soil degradation. *In* D.J. Greenland and T. Szaboles (ed). Soil resilience and sustainable land use. CAB Int., Wallingford.

Olsson, L., L. Eklundh, and J. Ardö. 2005. A recent greening of the Sahel: Trends, patterns and potential causes. J. Arid Environ. 63:556.

Pardey, P. G., N. M. Beintema, S. Dehmer, and S. Wood. 2006. Agricultural research: A growing global divide? Univ. Minnesota, St. Paul and IFPRI, Washington DC.

Pigato, M. 2001. Information and communication technology, poverty, and development in sub-Saharan Africa and South Asia. World Bank, Washington DC.

Pinstrup-Anderson, P., and M.J. Cohen. 2001. Rich and poor country perspectives on biotechnologies worldwide in an era of intellectual property. Minnesota J. Law, Sci. Tech. 6(1):213-252.

Reich, P.F., S.T. Numbem, R.A. Almaraz, and H. Eswaran. 2001. Land resource stresses and desertification in Africa. Agro-Science 2:1-10.

Swift, M.J., and K. Shepherd. 2007. Saving Africa's soils: Science and technology for improved soil management in Africa. World Agroforestry Centre, Nairobi.

Townsend, R.E. 1999. Agricultural incentives in Sub-Saharan Africa: Policy challenges: Technical Pap. 444. World Bank, Washington DC.

UN. 2006. The Millennium Development Goals report: Statistical annex 2006. Available at http://mdgs.un.org/unsd/mdg/Resources/Static/Data/UNSD%20MDG%20Report%202006%20Statistical%20Annex%20r15.pdf. Dep. Econ. Social Affairs, UN, Geneva.

UN Millennium Project. 2005. Halving hunger: It can be done: Summary version of the report of task force on hunger. The Earth Inst., Columbia Univ., New York.

UNECA. 1999. Economic report on Africa 1999: The challenge of poverty reduction and sustainability.UN Econ. Comm. Africa, Addis Ababa.

UNECA. 2005. Structural transformation to break away from rural poverty. Chapter 4 *In* Economic report on Africa. Available at http://www.uneca.org/era2005/chap4.pdf. UN Econ. Comm. Africa, Addis Ababa.

UNEP. 2002a. Africa environment outlook: Past, present and future perspectives. UNEP, Nairobi.

UNEP. 2002b. Vital water graphics [Online]. Available at http://www.unep.org/dewa/assessments/ecosystems/water/vitalwater/. UNEP, Nairobi.

UNEP. 2006a. Africa environment outlook 2: Our environment, our wealth. UNEP, Nairobi.

UNEP. 2006b. Global deserts outlook. UNEP, Nairobi.

UNEP. 2007a. Fourth global environment outlook. Chapter 6: Regional perspectives. UNEP, Nairobi.

UNEP. 2007b. Fourth global environment outlook. Chapter 3: Land. UNEP, Nairobi.

UNEP/DEWA/GRID. 2005. GeoData portal. Available at http://www.grid.unep.ch/data/index.php. UNEP, Nairobi.

Yager, T.R., P.M. Mobbs, O. Bermudez-Lugo, G.J. Coakley, and D.R. Wilburn. 2004. USGS minerals survey 2004: The mineral industries of Africa. Available at http://minerals.usgs.gov/minerals/pubs/country/2004/africa04.pdf. USGS, Washington, DC.

Wood, D., and J.M. Lenne (ed) 1999. Agrobiodiversity: Characterization, utilization and management. CABI, Wallingford.

World Bank. 2001. WDR 2000/2001: Growth, inequality and poverty. World Bank, Washington DC.

World Bank. 2006. World development report 2006: Equity and development. World Bank and Oxford Univ. Press, NY.

WRI. 2005. The wealth of the poor: Managing ecosystems to fight poverty. World Resources Institute, Washington DC.

2

Typology and Evolution of Production, Distribution and Consumption Systems

Coordinating Lead Authors:
Julienne Kuiseu (Cameroon), Lindela Ndlovu (Zimbabwe)

Lead Authors:
Michael Dike (Nigeria), Lutgard Kagaruki (Tanzania), Imelda Kashaija (Uganda), Dieudonne Musibono (Democratic Republic of Congo), Victor Ndirika (Nigeria), Xavier Rakotonjanahary (Madagascar)

Contributing Authors:
Wisdom Akpalu (Ghana), Patrick Avato (Italy/Germany), Sachin Das (Tanzania), Pedro Marques (USA), Peter Neuenschwander (Benin), Stella Williams (Nigeria), Charlotte Wonani (Zambia)

Review Editors:
Stella Bitende (Tanzania), Patrick Matakala (Zimbabwe)

Key Messages

Key messages

1. Land and water are considered by numerous SSA countries as key factors to improving the food security for their populations. The dependence of agriculture in SSA on rainfall is a major constraint for its productivity. Only 4% of arable land in the SSA region is irrigated compared to 35% in Asia and 15% in Latin America. Some efforts have been made by governments in respect to large scale irrigation schemes that require high levels of maintenance. Nevertheless, some of the initiatives undertaken did not deliver the expected results. There is ample scope for increased irrigation in many parts of SSA, particularly for small-scale irrigation and water harvesting. Additional financing and expertise are needed to extend irrigation, while avoiding some of the environmental, social and technical failures of the past. Low farm productivity observed in some SSA countries needs to be address through integrated management that combines increased use of organic and mineral fertilizers, good seed varieties, irrigation and mechanization, rather than applying each separately.

2. Chemicals (fertilizers and pesticides) in most SSA countries have had negative effects on human health and on the environment. In Benin there were 70 deaths in 2000 and 24 deaths in 2001 were recorded in the cotton-growing seasons due to poisonings by chemicals. Over 50,000 tonnes of obsolete stocks of chemicals have accumulated in African countries over the last four decades. Many of these chemicals and their containers are in poor condition and threaten local and regional environments through the contamination of soil, water, food and air. Increased literacy and basic training on how to use chemicals in a safe manner could reduce the harmful effects of chemicals on human health and the environment.

3. SSA has diversified farming systems. Climatic variations, types of cultivated crops, cultural practices, farmers' production objectives and other biotic and abiotic factors have contributed to the diversity of farming systems found in SSA. This has resulted in various cropping systems in SSA.

4. Animal and crop productivity and production increases in SSA are due, in part, to the utilization of genetically improved materials, which are well adapted to harsh conditions and tolerant to pests and diseases. Indigenous animal breeds of SSA are preferred due to their low management costs, as they can withstand harsh conditions and are tolerant to most diseases. However, their performance in terms of meat, milk and egg production has been low due to limited genetic potential and poor management. Advances in AKST have helped to improve the production potential of these animals, through record-keeping and individual identification for appropriate breeding purposes. Community-based characterization, conservation in gene banks and utilization of indigenous animal genetic resources through open nucleus breeding schemes, for example, are important. Community participation is essential for the extension and propagation of new breeds. Cowpea and sorghum grain yield increases of about 61%, and 46-50%, respectively, have been achieved since the first half of the 20th century. The SSA region has an enormous agricultural potential in its crop genetic resources through many centuries of adaptation to the environment. Conservation, characterization and utilization of this germplasm through conventional breeding as well as through new technologies are keys to providing more and higher yielding varieties. Other factors that have contributed to the increase in productivity include the use of improved good quality seeds, timely and adequate application of fertilizers, application of appropriate pest control measures and good market prices.

5. Improved local and traditional knowledge, available to most resource-poor farmers in SSA, is essential for management of animal and crop pests and diseases. The use of local and traditional knowledge has minimized post-harvest losses. In the absence of both conventional and improved local/traditional techniques, crop losses of 30-100% have been recorded.

6. Opportunities exist in Africa for harnessing fisheries and aquaculture in the fight against poverty. Fish contribute to the food and nutritional security of 200 million Africans and provide income for over 10 million mostly small-scale fishers and farmers and entrepreneurs engaged in fish production, processing and trade. In SSA, aquaculture output (excluding aquatic plants) between 1989 and 2001 increased from 33,360 to 55,375 tonnes. However aquatic resource management could be strengthened and fisheries value chain supported through strategic investments to safeguard these benefits. Aquaculture is growing albeit slowly and the prospects for expansion and for environmental and socioeconomic sustainability have greatly improved. The key role of AKST could be to ensure that stakeholders in the region get improved access to knowledge and technologies for product development and food safety that safeguard and widen market access for small and medium enterprises (SMEs).

7. The co-existence of humans and animals in SSA has resulted in competition for resources and transmission of zoonotic diseases. SSA has a sufficient animal population (ratio of cattle to humans of 1:4) to cater to human requirements. However, diseases affecting both humans and animals have been a great setback. The situation is aggravated by unregulated cross-border migrations which have resulted in huge economic losses due to the spread of transboundary diseases like contagious bovine pleuropneumonia (CBPP), African Swine Fever (ASF) and Rift Valley Fever (RVF). Nonetheless, advances in AKST have led to the eradication of some animal diseases like rinderpest and trypanosomiasis in some SSA countries.

8. Animal production systems and animal productivity varies in SSA due to environmental factors and farmer production objectives. In wet areas, mixed crop and animal production provide a sustainable production system because of nutrient cycling and has the potential, through intensification, to meet increased demand for livestock food products. In dry environments, the long-run primary productivity of the range is influenced more by rainfall than by grazing intensity of livestock or wildlife. In these environments, livestock and wildlife production systems have the potential to increase incomes and improve sustainable use of land not suitable for cropping, provided conflicts of resource use and disease transmittances are anticipated, planned for and mitigated or avoided.

9. Forests are important potential resources that need to be well managed for poverty alleviation within the SSA region. AKST, however, is not yet well integrated in forestry/forest management policies within the SSA region. Consequently, value-addition and fair trade of traceable timber and timber products is minimal. Limited research on forestry and agroforestry in SSA hampers the development of forest resources into income-generating enterprises that could alleviate rural poverty.

10. Biomass is the most important source of energy in Africa today, meeting more than 50% of its total primary energy consumption. Its use in traditional forms such as firewood results in inefficient energy conversion, environmental and health hazards and is time-consuming in terms of collection. Several options exist to modernize for the supply of more efficient energy services, among them liquid biofuels and electricity and heat from biomass.

2.1 Crop Production Systems in the SSA

In sub-Saharan Africa (SSA), agricultural production is mainly rainfed and farming systems are largely dependent on the broad ecological zones defined in large part according to changes in the intensity of rainfall and evapotranspiration. Crop production takes place under extremely variable agroecological conditions. For example, annual average precipitation ranges from less than 100 mm in the desert, northeast of Ethiopia, to 3,200 mm/year in Sao Tome and Principe, with large variations between countries (AQUASTAT, 2005). Climatic variations, types of cultivated crops, cultural practices, farmers' production objectives and other biotic and abiotic factors contribute to the variety of farming systems found in SSA (Dixon et al., 2001).

2.1.1 Land, soil and water management

Agricultural systems in many SSA countries are under threat because soils have been damaged, eroded or not well managed; water supplies are minimal and/or erratic; and some farming systems are inefficient. Land and water are (sometimes) the sources of conflicts between farmers and herders in arid areas of West and Central Africa. Crop damaged by herders' livestock, cattle corridors and grazing lands encroachment and blockage of water points by farmers are the predominant causes of small conflicts in SSA rural areas. Competition over land is cited as one of the main causes of farmer and herder conflicts (Downs and Reyna, 1988; Bassett and Crummey, 2003). Climate with frequent episodes of severe drought in the semiarid lands have led to serious degradation of vegetation cover and there are increasing threats of wind and runoff erosion and depletion of soil fertility on a large scale in many parts of sub-Saharan Africa. In such conditions, soils require chemical and manure amendments if they are to provide the higher yields needed for food security.

Soil and water are two important resources for all farming systems and their preservation is crucial to sustain agricultural production in sub-Saharan Africa. Their management is highly influenced by land use and tenure systems.

2.1.1.1 Land management

Sub-Saharan Africa has 2.4 billion ha of land with forest area estimated at 627 million ha (MA, 2005), of which over 5 million ha per year is lost (FAO, 2001). In the year 2000, roughly 20% of SSA's potential arable land was in cultivation. However, in some countries such as in Burundi, over 93% of the population is rural and entirely reliant on agriculture for their survival and income, hence most of the land, 90% of the total cultivated area, is devoted to food crops and 10% to export crops (Leisz, 1998). Land lies at the heart of social, economic and political life in most of SSA, but across many countries there is a lack of clarity regarding land tenure. National policies on land tenure systems are contested throughout the region.

SSA is nearly 34% pastoral, 30% forest and woodland and just under 7% of cropland (WRI, 1994). Another 30% is a small part urban and roads and the rest chiefly sand, rock and poorly vegetated terrain. However, the demand for cropland is highly variable and some countries have little room for expansion. The highest proportions of cropland and permanent pasture are in western and eastern Africa; the highest percentages of cropland by country are in Burundi (52.3%), Mauritius (52.2%), Rwanda (46.9%), Nigeria (35.4%), and Uganda (33.7%) (WRI, 1994). These countries, particularly Rwanda, have little scope for the expansion of agricultural production other than by intensification. It is worth noting that some of the countries with advanced commercial agriculture, e.g., Kenya and Zimbabwe, have only low to average proportions of cropland and Kenya has a considerable area with serious environmental limitations. Land use in SSA has also evolved over time from extensive uses of land to more permanent land use types.

In some part of pre-colonial Africa, land was mostly conceived of as a common resource to be used, not as a commodity to be measured, plotted, subdivided, leased, pawned or sold (Bohannan, 1963; Colson, 1971). For most of pre-colonial SSA, with its low population densities and relatively limited population movements, land was a resource that all community members should have access to in order to subsist. Subsistence remained the main motive for accessing land and disputes about land boundaries were insignificant. Community members had a ritual relationship to land and did not differentiate between land for agricultural and other purposes (Pottier, 2005). The population had developed efficient systems of land use compatible with their environment. Land use in tropical Africa has evolved from hunting and collection practiced by people such as the Pigmies in the Zaire/Congo Basins through shifting cultivation, widely practiced throughout SSA, to bush fallowing (Pritchard, 1979). These practices had the advantages of minimizing soil erosion, preserving agrobiodiversity, maintaining ecological stability and optimizing the utilization of different soil nutrients.

It was under the impact of colonialism that community leaders were made into landlords on the grounds that they were community leaders and therefore holders of the land rights of the community. The form of land tenure and the system of access rights in SSA became one of the most important issues related to land and the management of other natural resources. These policies had a direct effect on people's security and on their investment in soil and water management, which in turn affected productivity and land quality. Even where colonial governments pledged to respect existing customs, they encouraged a modicum of economic development that diverted some land to new uses and by stimulating an appetite for imported goods that could be met only by the exploitation of land in cash cropping (Pottier, 2005). The introduction of cash crops such as cotton, tobacco, tea, coffee, groundnuts, etc., during the colonial period, have resulted in the diffusion of modern, sedentary and commercial land use practices from European settler farmers to African farmers who started producing for the cash market. Settler colonial land expropriation varied in SSA. It was most extensive in Kenya, South Africa, Zimbabwe and Namibia, and occurred to a lesser extent in Mozambique, Swaziland, Botswana, Tanzania and Zambia (Moyo, 2005).

Access to land as well as the rights to its use is institutionalized by custom laws or national regulations. The conditions for the allocation of rights in traditional systems changes over time. They are the result of negotiations (e.g., between family groups with different interests) and conflicts (between agriculturalists and pastoralists) arising from new conditions such as: the introduction of new technologies; and the inclusion of actors such as the state or projects which enter a claim to resources (Kirk, 1996). In most SSA countries, men and women farmers do not have equal access to adequate land and the access of women is even more limited due to cultural, traditional and sociological factors. However, in most African societies women traditionally had use rights to land (Pala, 1976). The complex social and political contradictions of colonial and post-independence land policies have increasingly derogated the land rights of the poor, fuelling popular demands for land reforms (Moyo and Yeros, 2005). In Zimbabwe, land reforms led to a loss of land for women (Pankhurst and Jacobs, 1988). The marginalization of women in the allocation of irrigated rice fields to men in the Gambia adversely affected rice production and gender relations and also culminated in the failure of the project (Dey, 1981; Carney, 1988).

Despite the role of women as the backbone of food production in SSA, women are faced with many factors constraining their effective participation in achieving food security. Frequently, land of poorer quality or in unfavorable sites is allocated to women. In some parts of Nigeria, for example, women have restricted access to land, causing a major constraint (Ukeje, 2004). In the majority of patrilineal arrangements, the right to land expires automatically in the case of divorce or death of the husband. In Burundi for example, under customary law, women could not own or inherit land, they could only enjoy limited access bestowed through affiliation to the male legatees (Kamuni et al., 2005). In Sahelian countries Islam has opened an opportunity for women to access land through the right of inheritance (Kirk, 1996), as is the case in Senegal and Mali. Without land, women have no security and have to depend on land owners for employment.

A number of SSA land tenure systems have been identified (White, 1959). They included societies in which an individual obtains land rights by residence, without allocation through a hierarchy of estates (this was the most prevalent type of land tenure in pre-colonial period); land holding under the control of lineages where access to agricultural land was exclusively reserved for use by members who traced their heritage from a common ancestry (in Zambia, Ethiopia, etc.); societies in which Chiefs exercised direct control over allocation of land with a descending hierarchy of estate (example of the Mossi empire in Burkina Faso); feudal systems with landlords and tenants (some parts in Uganda, in Ethiopia) and the individualized land tenure under commercial production (appearing during the colonial period in most part of SSA).

Land use in SSA has evolved over time, from uses involving extensive tracts of land to more permanent land use types. In the same way, land tenure has also evolved from communal types to those in which individual land rights are more clearly expressed and even enshrined in law, such as under titling programs in countries like Kenya (Birgegard, 1993). The subsistence or shifting forms of land use and the communal forms of land tenure remain in practice in sparsely populated areas. Inadequate land tenure structures are still a major obstacle to sustainable agriculture and rural development in many countries. In particular, women's access to land remains an unresolved issue in a number of cases.

2.1.1.2 Soil management

Traditional and rudimentary technologies consisting mainly of hoe and cutlass were the main land preparation systems in the pre-colonial era in SSA. These systems continued during colonial, independence and post-independence periods as the majority of farmers are still smallholder farmers. Slash and burn practices contributed to maintaining soil fertility. Colonial administration brought agricultural machinery consisting primarily of tractors and animal traction. Sloping terrain does not permit the use of modern technology and where possible, poverty seems to be the primary reason for low application of modern technologies. In most SSA countries today, farming activities are carried out mainly with traditional and rudimentary technologies. For every 100 ha of arable land, only one tractor is available in Rwanda compared to 175 in Botswana or 20 in Tanzania for (Musahara and Huggins, 2005). It is estimated that there are about 10,000 tractors in Nigeria, out of which 50.5% are broken down. Nigeria's tractors have been calculated to operate at 0.03 horsepower per hectare compared with FAO recommended tractor's density of 1.5 horsepower per hectare (Ukeje, 2004). Fertilizer tends to be used mostly on cash crop and plantation crops because of the high profitability of fertilizers in the production of export or high value crops. Synthetic fertilizer consumption grew at an annual rate of 4% from 1961 to 2002, but growth rates declined from about 6% between 1961 and 1989 to only 1.3% from 1990 to 2002. These figures mask a great deal of variability among SSA countries. For example, from 1998 to 2002, four countries accounted for 62.5% of all SSA fertilizer consumption: South Africa (38.8%); Nigeria (8.7%); Zimbabwe (7.6%); and Ethiopia (7.4%) (Ukeje, 2004; Kelly, 2006). Mineral fertilizer consumption in Niger is the lowest in the world and amounts to only 0.3 kg of plant nutrients per hectare on average (World Bank, 1997). Limited financial means and the lack of subsidies seem to be the primary reason of the absence or low application of fertilizers and chemicals.

To date, fertilizer use in SSA has not led to increases in agricultural productivity on the scale observed elsewhere. Fertilizer consumption is only 9 kg ha^{-1} within the region compared with 73 kg ha^{-1} in Latin America, 100 kg ha^{-1}in South Asia and 135 kg ha^{-1} in East and Southeast Asia (FAO, 2004a). Such low levels of fertilizer use, combined with shorter fallow periods and insignificant organic fertilizer inputs represent a serious threat to agricultural sustainability. African soils are being steadily depleted of nutrients due to farming without fertilizers (Matlon, 1987; Stoorvogel and Smaling, 1990; Van der Pol, 1992; Cleaver and Schreiber, 1994; Sanders et al., 1996; Steiner, 1996; Buresh et al., 1997; Sanchez et al., 1997; Smaling et al., 1997; Bationo et al., 1998; Eswaran et al., 2001). Fertilizer use is projected to need to increase in SSA from 9 to at least 30 kg ha^{-1} during the next decade, but increased use may have undesirable environmental impacts such as soil acidification, water pollution and health problems.

No single approach is sufficient to improve soil fertility in SSA. Integrated soil management, combining organic fertilizers (compost, manure, green manure) and reasonable quantities of synthetic fertilizers is an approach adaptable to locally available resources. Recent research on marginal soils in Burkina Faso by ICRISAT has shown that it is possible to increase millet and sorghum yields profitably by using inorganic fertilizer in combination with techniques that conserve and concentrate soil moisture and organic matter (http://www.icrisat.org/gt-aes/IFADPamph.pdf).

Due to different agroecological regions, farmers in SSA use a wide variety of traditional soil and water management techniques. An intensive system of soil and water management was developed over centuries by the Mandara population in the northern uplands of Cameroon and the Dogon people of Mali to restore and maintain soil fertility (Roose, 1994). This system includes terraces, alignment of stones, small dams, drop pipes of irrigation, wells and microdikes combined with agroforestry, compost, mulch and crop rotations. The Dogon people of Mali developed a series of soil and water management methods. The indigenous agronomic practices of the Kuba and Zande peoples in the Congo involved cassava, cereals and legume rotations; the Sonjo of Tanzania used a sweet potato, cereals and irrigation complex; the Lugbara used a cassava, cereals, legumes and banana complex in Uganda; and in West Africa, rice, tubers and legumes formed the base of an agronomic complex (Kajoba, 1993). These techniques are sustainable at low population pressures. There is impressive historical evidence of the ability of pre-colonial societies in SSA to adapt production systems and livelihood strategies to local ecological conditions resulting in environmental sustainability.

In some SSA countries, programs were imposed during the colonial and post-colonial eras to solve wind and runoff erosion and water problems. This is the case in the region of Machakos in Kenya, where a program of terrace-building was imposed during the fifties and led to the yearly building of about 5000 km of new terraces (Tiffen et al., 1994; Mortimore and Tiffen, 1995). In Zimbabwe, colonial authorities had imposed the building of more than 7000 km of small breakwaters between 1929 and1938. This practice continued until 1957, totaling more than 200,000 ha of communal lands (Whitlow, 1988).

The same policies were followed in Malawi where 118,000 km of small breakwaters were built between 1945 and 1960 (Stocking, 1985) and in Zambia's eastern province where many projects were accomplished in the forties and fifties (Mukanda and Mwiinga, 1993). In many cases, measures of sustainable land and water management were rejected by the local population (for example in Zimbabwe) because they were not involved in the process. However, in some regions, techniques and practices had been broadly adopted by farmers anxious for investments to transform their farming systems, as is the case of the Machakos in Kenya. Throughout the region until post-independence, land uses were affected by imposed programs and technologies.

International Institute of Tropical Agriculture (IITA), International Livestock Research Institute (ILRI), International Crops Research Institute for the Semiarid Tropics (ICRISAT), International Centre for Research in Agroforestry (ICRAF) and other research centers, governments, universities and NGOs have been working with farmers and national scientists to identify appropriate solutions to increase productivity in sustainable ways. A number of promising technologies, such as natural resource management (NRM), integrated soil fertility management (ISFM), improved land husbandry (ILH), soil and water conservation (SWC) and conservation agriculture, have been developed and adopted with some success. Mucuna (*Mucuna pruriens* [velvetbean]) cover cropping is an example of a simple regenerative component for farm systems that can adapted by farmers for local conditions. It has helped many farmers ameliorate soils in maize systems.

Burkina Faso, Mali and Niger have seen remarkable transformations of formerly degraded and abandoned lands with the adoption of traditional water-harvesting techniques, for example, tassas in Niger and zaï in Burkina Faso. The average family in Burkina Faso using the zaï technology has moved from annual cereal deficits of 644 kg (equivalent to 6.5 months of food shortage) to producing a surplus of 153 kg per year (Reij, 1996).

2.1.1.3 Water management

Water scarcity is becoming one of the major limiting factors to economic development and welfare in large parts of sub-Saharan Africa. Unfavorable climatic factors such as erratic rainfall, high evaporative demand, several drought series, etc., contribute to water scarcity. In areas where the climate is hot and dry (e.g., the Sahel region), irrigated lands are subject to substantial water losses through evapotranspiration. Salts contained in precipitation and irrigation water remain in the soil and increase in concentration when the water evaporates from the soil or when the plants take up water for transpiration. If the salt is not leached from the soil, the salt concentration increases constantly, subsequently causing reductions in crop yield.

Sub-Saharan Africa lags far behind the rest of the world in proportion of irrigated arable land and its contribution to total food production. In terms of value, irrigation is responsible for an estimated 9% of the crops produced in SSA (Yudelman, 1994). Irrigation development in SSA was initiated during the colonial period with the construction of irrigation schemes by private companies from Europe in the major river basins and also in the inland valleys for the production of tropical fruits and vegetables for European markets. After independence, public sector irrigation schemes have been accompanied by a growing number of new initiatives by private sectors. The management of the irrigation systems is generally ensured jointly by the state, as regards the primary infrastructure or public systems and by users associations for the secondary and tertiary infrastructure, or by private systems. The disengagement of the state from the irrigation sector since the 1980s and the subsequent creation of user associations (in place or planned in South Africa, Burundi, Côte d'Ivoire, Ghana, Madagascar, Mali, Mauritius, Niger, Nigeria, Senegal, Swaziland and Zimbabwe), as well as the more recent promotion of participatory approaches (Burkina Faso, Mauritania and Chad) concerns about 20 African countries. The example of Kenya illustrates the choice of management transfer; all new irrigation schemes created between 1992 and 2003 are private, while some former public schemes are still partially administered by the state.

Most large-scale irrigation schemes and soil conservation projects attempted in sub-Saharan Africa in the past have met with little success (Bonkoungou, 1996). They have generally been expensive to construct and maintain and their performance has been disappointing. Not only have production increases been lower than anticipated, but systems have often been unsustainable, due to low output prices and high operation and maintenance costs. Examples include the Office du Niger in Mali, the Awash Valley scheme in Ethiopia and the Jahalya Pacharr scheme in the Gambia. Countries that have already developed their irrigation potential, such as South Africa, no longer carry out construction work, rather, they have undertaken the development of more efficient techniques for water use (sprinkler and localized irrigation) with the aim of reducing the water volume used for crops (AQUASTAT, 2005).

Yet water management is less advanced in sub-Saharan Africa than in any other developing region. The percentage of arable land that is irrigated is about 4.0% compared to 37% in Asia and 15% in Latin America. This figure that rises to 7% in Africa as a whole given that 40% of the total irrigated area is in North Africa (NEPAD, 2003). The irrigated area in SSA is concentrated in South Africa (1.5 million ha) and Madagascar (1.1 million ha). Nine other countries (Nigeria, Ethiopia, Mali, Somalia, Tanzania, Zimbabwe, Senegal, Zambia and Kenya) each have more than 100,000 irrigated hectares. About half of the irrigated areas are small-scale systems. Equatorial Guinea has no irrigation because of the climate conditions. In 2002, Madagascar had about 1,086,000 ha of irrigated areas representing 30.6% of total cultivated areas. Water is collected mainly from dams, or diversions from rivers or channels and dispatched by gravity. In 2000, irrigated rice with total or partial water control had grown to over 1,062,000 ha, representing about 75.8% of total rice areas. Other irrigated cultures are cotton (0.11%) and sugar cane (0.22%). About one third (28.2%) of the irrigated rice areas are traditionally managed i.e., by family groups, without government intervention. They are scattered in the inland valleys and each perimeter rarely extends over 10 ha (FAO, 2005a). This irrigation system is similar to Asian farming practices. Irrigation water is essential for puddling the rice field while drainage is needed for avoiding rice plant withering. Vegetables are grown after rice using residual soil moisture.

One way forward is to effectively build on local knowledge, institutions and solutions for better water management such as integrated water resources management and the development of small-scale irrigation. Some policies and legislative proposals include integrated water resources management schemes, which, accompanied by practices that protect water resources, could help to guarantee their long-term sustainability. With regard to the number of smallholder farmers in sub-Saharan Africa, different stakeholders (governments, public sector, private sector, NGOs, farmer organizations, etc.) could work to improve the efficiency of traditional, small-scale systems by maximizing available rainfall and soil management strategies that build water holding capacities, promote greater water infiltration and percolation, reduce runoff and decrease evaporation through mulching and conservation tillage. Madagascar is one of the leading countries in sub-Saharan Africa in achieving irrigation potential (Yudelman, 1994). Many of the irrigation systems in Madagascar have Asian farming components and such systems may be relevant to and beneficial for other SSA countries.

2.1.2 Crop genetic resources

Small-scale farmers traditionally exchange seeds among themselves. This system of seed exchange prevailed in the past and was an efficient way to release crop varieties and spread agricultural knowledge.

Like in other parts of the world, cereals are the most important food crops; however, the sub-Saharan region also has its specificities. Crops grown in the region may be classified as cereals (maize, sorghum, rice, millet (*Pennisetum glaucum*), pulse (beans, cowpeas, chickpeas, pigeon peas), oil crops (groundnut, soybean), roots and tubers (cassava, sweet potato, yam, potato) and tree crops such as plantain and banana. Cassava, yam and plantain are staple food crops essential to food security in the humid and subhumid tropics of Africa (Asiedu et al., 1992). Commodity priority is varying at the sub-regional level; the order of priority could be based on the number of countries citing the commodity and the priority rank they give to it (ASARECA, 2006a). Among cereals, millet and sorghum are common in drier areas of the northern part of SSA and wheat is mainly grown in the eastern subregion (Kenya, Tanzania, Uganda) and in South Africa, with teff in Ethiopia. Rice has become increasingly important in the SSA region, both as a food source and as an economic commodity and is now the most rapidly growing food source in Africa (WARDA, 2003). In Madagascar, rice is the staple food and is eaten three times a day as the main ingredient (IRRI, 1993). Among legumes, which are usually grown in mixed cropping systems in the SSA, cowpeas are mostly found in the western sub-region mainly with sorghum and millet (Singh et al., 1992), while beans are found more in the eastern subregion (Allen and Smithson, 1988; Bokosi, 1988).

The SSA region also possesses an enormous crop genetic resource potential. For example, edible yam accounted for 95.6% of the total world output of the crop (Okoli, 1991). A special mention should be made to Ethiopia, which is known as a Vavilovian center of crop domestication and diversity for several important plants; it has 12 potentially valuable crop plants, such as the root and tuber crops enset (*Ensete ventricosum*), anchote (*Coccinia abyssinica*), oromo dinich (*Coleus edulis*), the vegetable okra (*Abelmoschus esculantus*) and the legume crop yeheb (*Cordeauxia edulis*) (Demissie, 1991). Enset is the most important staple food in southwestern Ethiopia, where its cultivation is restricted; the sources of food are the pseudostem and the corm. Tubers of oromo dinich are usually boiled and consumed as a vegetable. The seeds of yeheb are roasted or eaten raw; they have high protein content (13%), fat (11%) and starch (13%).

Trends in crop genetic resource contributions within cropping systems. In the SSA region, the performance of crop genetic resources is limited by many biotic and abiotic constraints such as pests (e.g., rice yellow mottle virus and gall midge on rice), drought stresses, low soil fertility due to small organic matter content and soil erosion, soil toxicity (e.g., aluminum toxicity) or nutrient deficiency (e.g., phosphorus deficiency). Moreover, there is a lack of appropriate equipment for land preparation and postharvest operations, inadequate and irregular input supplies (seeds, fertilizers, pesticides) and lack of credit. In Madagascar, irrigated rice yields have been stagnant due to low levels of fertilizer application (WARDA, 2005a).

During the pre-colonial period in the SSA, crops were traditionally grown in mixture; for example, cereals were grown with groundnut. In small areas, sole cultures were grown; the varieties used were usually mixed but usually had common traits, which were related to yield stability, consumer preferences and low input use. In general, they had satisfied the food needs of the populations because the demand was below the level of crop production. As crop production was primarily for subsistence, characteristics of high productivity or for exports were not considered or ignored. However, traditional agriculture is an important source of genetic diversity; and it offers enormous possibilities for the creation of high yielding varieties.

In the colonial period, monocropping was the trend, with a focus on cash commodities for export. Crops became homogeneous and genetic diversity was lost. In Madagascar, rice varieties with long, white and translucent grains were promoted both for local market and for export, at the expense of the traditional red kernel rice varieties. In the large scale farming systems, crop productions were transformed and industrialized; for example, cassava starch was processed to tapioca. Crop genetic resources during this period were improved by conventional methods (mass selection and hybridization). In order to have market accessibility, there was a trend in the use of commercialized seeds with high varietal purity. Thus, crop genetic resources have greatly contributed to the success of exports.

When most colonized countries acquired their political independence between 1960 and 1971 under the auspices of the United Nations, the Consultative Group on International Agricultural Research (CGIAR), a worldwide network of international research centers, was founded with the mission to contribute to food security and poverty eradication in developing countries through partnership with national governmental and nongovernmental organizations, universities and private industry. In the SSA region, the International Institute of Tropical Agriculture (IITA), in Ibadan, Nigeria and the West Africa Rice Development Authority (WARDA) in Cotonou, Benin were established to conduct research on tropical crops and rice as mandated commodities. Evaluation and improvement of cowpea (or niebe, *Vigna unguiculata*) and tuber and root crop germplasm (e.g., cassava, sweet potato, yam) are undertaken at IITA. IITA is also the major research center for bambara groundnut germplasm, which is a neglected crop with a high nutritional value (Goli et al., 1991).

The International Crops Research Institute for the Semiarid Tropics (ICRISAT), which is based in India, has also assembled many germplasm samples from African countries for use in plant breeding, namely sorghum, pearl millet, chickpea, pigeon pea, groundnut and minor millet (Mengesha and Rao, 1991). The Centro Internacional de Agricultura Tropical (CIAT, International Centre for Tropical Agriculture) in Colombia, South America contributed to the improvement of African cassava (Allem and Hahn, 1988) and on promotion of new varieties of bean (David, 1998).

In the 1960, through the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) and the International Rice Research Institute (IRRI), the introgression of dwarfism genes respectively in wheat and in rice, led the world to the Green Revolution (Gotoh and Chang, 1979). Whereas these high-yielding varieties of wheat and rice were rapidly adopted and commercialized, farmers in the developing world, including farmers in the SSA region, did not profit from the Green Revolution because of the sharp increase in oil and fertilizer prices during the 1973 oil crisis (Zwartz and Hautvast, 1979). For rice crops, the Green Revolution required good irrigation infrastructure and water management, which were absent in most countries of the SSA region; in fact, the performance of irrigation schemes previous to this period was disappointing (see 2.1.2, Water management). Green Revolution technologies assume intensive use and timely applications of inputs and seeds of high-yielding varieties, which were not within the reach of farmers because of many social and economic factors (high price of inputs, absence of rural markets for timely delivery, lack of information, communication, illiteracy, etc.).

However, crop genetic resources continued to be improved by research institutions. They became resistant to multiple diseases and to insects and had higher productivity. Some have improved nutritional quality and higher commercial value, for example hybrid maize varieties with herbicide resistance or with less aflatoxin; cassava varieties resistant to cassava brown streak disease; *Dioscorea alata* and *D. rotundata* with high iron and zinc content in the tubers; and plantain banana resistant to black Sigatoka (IITA, 2004). About 400 improved varieties of sorghum and 40 groundnut strains were developed and have been released by ICRISAT (Ntare et al., 2005).

Extensive research has also been carried out by NARS and by research institutions from the North (Canada, US, several European countries, etc.) working in SSA countries. Some typical examples are the evaluation and improvement of coffee by ORSTOM (Berthaud and Charrier, 1988), the improvement by NARS of rice lines tolerant to iron toxicity in Ghana (Owusu et al., 1999) and the release for large-scale production of two accessions of kafirs (sorghum races from South Africa) in Ethiopia (Menkir and Kebede, 1984). Following this trend, a drawback was observed: after the political independence of former African colonies, some edible wild plants, e.g., *Dioscorea praehensilis*, were forgotten and replaced by recently introduced species.

Agricultural production has stagnated or declined in important food crops such as cereals, tubers and legumes. Crop yields and productivity in most African countries are about the same as 20 years ago. In 1998, cereal yields in sub-Saharan Africa averaged 1 tonne ha^{-1}, 15% lower than the world average of 1.2 tonnes ha^{-1} in 1965. Cereal yield was stagnant around 1 tonnes ha^{-1} from the 60s to 2000 in the SSA region (Eicher et al., 2005). This raises the question of whether or not farmers are using improved crop genetic resources.

Improved genetic resources were released by international research centers and NARs through preliminary varietal trials (PVT), extension services and pilot farmers. An impact study of new extra-early maize varieties adapted and released in the Sudan savanna of Nigeria was completed; the adoption rate (14%) was found to be low (IITA, 2004). Scarcity of seed and little seed exchange farmer-to-farmer were evoked as the reason for low adoption. Farmers have limited access to seeds of newly bred modern varieties. The supply of breeder, foundation, certified and commercial seed of varieties preferred by farmers or required by the markets is limited. Seed demand is also uncertain and weak; thus, seed production is not profitable. In addition there is poor integration between seed and product markets (Ntare et al., 2005).

To ensure food security in the SSA region, the widespread adoption of improved crop genetic resources requires favorable government policies and profitable markets for crop production. Seed regulations are currently inconsistent between the national and subregional levels. Harmonization of seed regulations may facilitate the movement of improved seeds within the subregion, could help maximize the use of limited technical and infrastructural capacities and reduce unnecessary duplication. Seed delivery for promising genetic resources can be strengthened through regional participatory approaches. The West Africa Seed Network (WASNET) and East Africa Seed Committee (EASCOM) promote seed development at local, national and regional levels in the framework of NEPAD. Potential food crops in the SSA region should be preserved and evaluated for important characteristics such as food value and ability to withstand stresses and protected from genetic erosion by natural calamities such as drought and desertification.

GMO (genetically modified organism) and non-GM technologies exist for improving crop genetic resources. For example tissue culture has enabled the improvement of plantain banana and rice (Dhlamini, 2006). Commodities for which GMO varieties are available for commercial production include maize, cotton, canola, Irish potatoes, tomatoes, papaya, squash, soybeans and rape (ASARECA, 2006c).

In the SSA region, South Africa is the only country growing GM crops commercially; areas under GM maize increased from 14.6% in 2005 to 29.4% in 2006 (ASARECA, 2006c). None of the COMESA/ASARECA countries has yet given approval for the commercial release of any GMO crops. Perceptions on GMOs include unexpected results such as environmental contamination and human health concerns (e.g., application of more pesticides when working with a pesticide resistant crop), biodiversity conservation (Persley, 1990) and problematic for organic certification if farmers plant GM crops due to potential cross fertilization with other plant varieties which cannot be controlled.

There are arguments against the use of GMOs and particularly the potential introduction of "terminator" technology (Genetic Use Restriction Technology), seeds that have been genetically engineered to produce sterile seeds at harvest. According to many scientists, molecular biocontainment systems (such as "terminator") are not a reliable mechanism for preventing escape of transgenes and have not been proven 100% effective (NRC, 2004; Heinemann, 2007). Many other concerns have been raised about further concentration of corporate control over seed supply. Further concerns involve farmer decision-making power, as contractual prohibitions and patent violations on Intellectual Property Rights (IPR) could terminate the right of farmers to sell or share common seeds (FAO, 2004b).

The minimum requirement of the Cartagena Biosafety Protocol, which allows unrestricted import of living GMOs intended for food use (or feed or processing), may increase the chances that some GM maize grains are planted. Many countries in Africa are utilizing tissue culture in their research and others have GM products in the pipeline (e.g., Kenya with maize stemborer resistant, Uganda with banana nematode and sigatoka disease resistance) (ASARECA, 2006c). Some stakeholders, including agricultural policy makers and biotechnology scientists in SSA consider GMOs as an option in accelerating agricultural development and increasing domestic food productivity in the region. A key question is "what is the cheapest source of new cereal crop technology in Africa: old fashioned plant breeding or GM research?" (Eicher et al., 2005). The importation of GM seeds is not yet officially restricted. If adopted, the use of GM seeds should proceed cautiously and the minimum standard set by the Cartagena Protocol should be applied so that risk associated with planting GMO seeds is minimized (ASARECA, 2006c).

2.1.3 Crop production systems, quality of production and productivity

Agricultural crop production plays a major role in ensuring food security, good nutrition and poverty alleviation in the sub-Saharan Africa (SSA). Inadequate crop production has over the years resulted in malnutrition and widespread poverty in parts of the region. Crop production systems that have been utilized within the region have also been inadequate and have resulted in low crop quality and productivity.

Typology of cropping systems. Climatic variations, types of cultivated crops, cultural practices, farmers' production objectives and other biotic and abiotic factors have contributed to a number of farming systems found in SSA (Dixon et al., 2001). Cropping systems in SSA are classified according to a number of specific features, such as water supply, type of rotation, cropping pattern and animal activities, degree of commercialization and tools used for cultivation (Ruthenberg, 1980).

Classification according to water supply. In classification according to water supply, two main types of farming are distinguished, namely irrigated farming and rain-fed farming. Most of the farming in SSA is rain-fed, although limited irrigation farming is practiced for a few crops such as rice and some horticultural crops. Most rice production in SSA, both upland and swamp rice, has been rain-fed. Other crops grown under rain-fed farming include cotton, cassava, sorghum, groundnuts, soybeans, sesame, yams, maize, bananas and plantains. An important part of crop production in SSA occurs on wetlands in valley bottoms and lowlands where water is captured without artificial irrigation.

Classification according to type of rotation. Various natural fallow systems are practiced in SSA, whereby cultivation alternates with an uncultivated fallow and may take the following forms: Forest fallows comprised of woody vegetation and closed canopies, in which trees are ecologically dominant; bush fallows comprised of thick vegetation in which shrubs are ecologically dominant; savanna fallows comprised of a mixture of fire-resistant trees and grasses; and grass fallows, comprised of grasses without woody vegetation.

Classification according to cropping pattern. There are two main types of cropping patterns, mixed cropping and monocropping. Mixed cropping with different crops grown at the same time in a given field is common in SSA with differences in technique. Mixed cropping appears to be the more effective way of reducing the risks of hunger and ensuring food security as it has the advantage of crop diversification (Ruthenberg, 1980). The common mixed cropping found in SSA are legumes/cereals, coffee/fiber crops, legumes/fiber crops.

Monocropping is practiced mainly in commercial farming and has the advantage of increased yield of particular crops. For instance, increased cowpea production has been obtained over the years due to a change from the traditional intercropping system to monocrops of cowpea and strip cropping involving two rows of cereals and four rows of cowpea (Singh and Ajeigbe, 2002). This improved intercropping system minimizes shading from the cereals crops and maximizes gains from limited application of fertilizer and agrochemicals.

Classification according to degree of commercialization. Three broad classifications are used: subsistence farming; partly commercialized farming; and commercialized farming. In SSA, 70% of agricultural production is subsistence farming and little commercialized farming occurs.

Classification according to implements used for cultivation. The three main classifications are: hoe-farming; farming with ploughs and animal traction; and farming with ploughs and tractors. Most of the subsistence farming in SSA is done by hoe-farming, but in some cases ploughs and animal traction are used as well. Commercial farming is done by ploughs and tractors.

Examples of Major Food and Cash Crops in SSA

Groundnut. Groundnut (*Arachis hypogaea* L.) is important both as an earner of foreign exchange as well as a source of good quality food. Groundnut is a leguminous oil crop, of high nutritional value, containing about 25% protein and 40 to 45% oil (Harkness, 1970). It is the most important source of vegetable oil and fat in SSA. Groundnut is thus a vital source of energy and contributes to dietary protein available for the control of various protein-deficiency diseases in the region. It is consumed in various forms in SSA including groundnut oil, roasted groundnut, oiled or raw groundnut and as ground or paste. Groundnut production in the SSA before the 1960s was low due to farmers growing the crop with minimum inputs using traditional local groundnut varieties as a component of mixed cropping systems. This trend continued in the region until the 1960s when, due to improved crop management practices and increase in harvested acreage, groundnut production increased to export levels. Groundnut production in SSA increased in the 1960s up to 1970. While world groundnut production continued to increase from the 1970s to the 1980s, SSA had a 17% decrease in production, with eastern and southern Africa being the main contributors to this loss due to changes in harvested area (-13%) and yield (-5%) (Fletcher et al., 1992). This trend has continued to the present.

The decline in production in SSA has been due to non-adoption of improved groundnut varieties, untimely and inappropriate use of farm inputs, low plant population and poor crop husbandry (Schilling and Misari, 1992). Decline in groundnut production can also be linked to low world market price because of substitution by soybean and sunflower oil. Other factors include unfavorable climatic conditions characterized by frequent droughts, high temperature and a decline in soil productivity due to continuous cultivation. Increases in grain yield have resulted from the use of pest resistant and high-yielding varieties and appropriate cultural and pest control measures.

Maize. Maize (*Zea mays* L.) is one of the most important staple foods in SSA. It is also one of the cheapest sources of energy readily available to poor people and rural dwellers in SSA. The grain contains 79% carbohydrate, 9% protein and 4% fat (NRC, 1979). Maize is also in high demand for livestock feed and for production of alcohol in the brewing industry. It serves as a raw material in textile and paper industries.

Maize production in the SSA grew slowly until the early part of the 20th century when it became popular with farmers (De Vries and Toenniessen, 2001). Maize production trends in SSA have fluctuated since the 1960s. Eastern and southern Africa are the predominant maize growing regions, with about 6 million tonnes produced per year until approximately 1985 (FAO, 2000c). West Africa, which produced about 2.5 million tonnes of maize until 1985, saw a 15.4% growth in maize production until 1989, while eastern Africa had no growth in production during this period. Growth in maize production dropped in SSA in the 1990s from 7.3% to 0.5%, resulting in a critical imbalance between maize production and the increasing human population (about 3% per annum) (FAO, 2000c). This period was followed by a phenomenal increase in maize production in SSA, especially in Nigeria, due in part to the availability of improved hybrid maize varieties from IITA. In the 1980s and early 1990s, small-holder maize expanded rapidly at the expense of sorghum and root crops, especially in the more northern drier part of the Guinea Savanna, as a result of diffusion of early-maturing maize varieties (Dixon et al., 2001). Reductions in yield are generally due to environmental stresses such as drought, low soil fertility and the parasitic weed, *Striga hermonthica*, pests and diseases, and inadequate access to fertlizers.

Sorghum. Sorghum (*Sorghum bicolor*) is an important staple food and a major source of energy in SSA. It contains three major macronutrients, 74% carbohydrate, 9 to 12% protein and 3% fat (Kochlar, 1986). Following the high cost of wheat and its low production in SSA, sorghum has been used to make nonwheat bread, which is cheap and readily available. Sorghum is used for the production of cake, sausage and biscuits as well as industrial lager beer and locally brewed alcohol. Sorghum is drought-resistant and mainly grown in the semiarid tropics as it is able to cope with drought stress.

Sorghum grain yields in SSA had been low up to the first half of the 20th century, with yields of between 500 to 800 kg ha^{-1} (Sharma and Nwanze, 1997). The main factors responsible for this low yield have been pests, diseases, weeds (especially *Striga hermonthica*) and severe drought.

Rice. Rice (*Oryzae sativa* L.) is an important staple food and is crucial to the economy of many countries in SSA. Rice contains 91% carbohydrate, 7% protein and 0.4% fat (Grist, 1953). The protein lacks sufficient essential amino acids (e.g., methionine, lysine and threonine) and is hence nutritionally inadequate (Chandler, 1979). It is however, a good source of energy for a majority of the populace in SSA as its carbohydrate is easily digestible. It also has enduring palatability and has been used consistently in meals. Rice production in SSA in the pre-colonial era was low as the crop was grown in small areas by resource-poor farmers for subsistence. Rice production increased from the beginning of the 20th century as the crop became not only a subsistence crop, but a source of income for farmers. Rice production in SSA increased slowly in the 1960s from 4 million to over 5 million tonnes in the 1970s, before a sharp rise to over 10 million tonnes in 1990s. This was followed by a fluctuating increase up to 2000 (WARDA, 2005b). Presently, West Africa is the predominant rice producing region, with the bulk of its production coming from Nigeria. Production levels in Southern Africa are highly influenced by Madagascar, while in Eastern Africa, Tanzania accounted for 80% of rice production. In Madagascar, the development and diffusion of the System of Rice Intensification (SRI) has resulted in very high rice yields up to 17 tonnes ha^{-1} (Uphoff et al., 2002).

Reduction in yield has been due to environmental stresses such as drought especially in nonirrigated rice, low soil fertility, weeds, insect pests and diseases. Non-utilization of available AKST due to low literacy levels has been one of the contributing factors to low yields recorded before the 1960s. Improved rice varieties are now available in SSA from West African Rice Development Authority (WARDA), following several years of research.

Cowpea. Cowpea (*Vigna unguiculata* L. Walp) is an important food legume and an essential component of cropping systems in SSA. Cowpea is an important source of nourishment especially for poor people who cannot afford animal protein. Cowpea contributes to soil fertility through its ability to fix nitrogen, which remains in the soil and contributes to subsequent crops. Cowpea haulms contain over 15% protein and constitute a valuable source of fodder for livestock (Dike, 2005). Cowpea production in SSA before the 20th century and in the first half of the century had been low mainly due to the use of local cowpea varieties and traditional farming systems. Increased production of cowpea has resulted in an increase in the quality of food available in SSA. This has ensured healthier livelihoods through the reduction of diseases such as kwashiorkor and protein energy malnutrition. As a legume with high protein content, it has proved an essential dietary component for the mitigation of diseases such as diabetes.

Mean cowpea grain yields in traditional intercropping systems range from 0 to 132 kg ha^{-1}, depending on the fertility level of the fields (Van Ek et al., 1997), compared with a sole cowpea yield potential of 1,500 to 3,000 kg ha^{-1} under optimum management (Muleba and Ezumah, 1985).The use of improved cowpea varieties, an increase in harvested areas and improved crop cultural practices have contributed to increases in production. Drought stress and poor soil fertility have been important factors resulting in reduced cowpea yields.

Horticultural crops. Many horticultural crops are grown in SSA. These include vegetable crops such as tomatoes, onions, peppers, garlic, eggplants, lettuce, carrots, watermelons, melons, cabbage, spinach, pineapples, apples, bananas, plantains and potatoes, and several fruit trees such as mangoes, guava, cashew, oranges and other citrus crops. These crops are rich in vitamins A, C and E and contribute to the quality of local diets and nourishment available for the maintenance of good health in the increasing population in SSA. Horticultural crops also have export value and contribute immensely to the export earnings of several countries in SSA. Tanzania is the largest exporter of horticultural crops in East Africa with cashew nuts alone accounting for 70% of horticultural export. Crop yield and export of horticultural crops has continued to increase over the years (FAO, 2004c). Export markets offer strong prospects for expanding the horticultural industry in SSA.

Production constraints for horticultural crops in SSA include pests and diseases and lack of access to improved high yielding plant varieties. Horticultural crops have exacting requirements. It is necessary for producers to use good cultural and agronomic practices in order to produce high quality and value products for export.

Coffee. Coffee is an invigorating stimulant taken as a beverage worldwide. Owing to its high market price coffee is grown by farmers in SSA mainly for export since around the end of the 19th century. As a cash crop, it has contributed to improving the economic status of many resource-poor farmers in SSA. Arabian and robusta high quality coffee are cultivated. Coffee production up to the first half of the 20th century was mainly practiced by small-scale farmers. Coffee production continued to increase gradually over the years with the small holders playing an important role in overall production. In Kenya, for instance, coffee production increased from 14,000 to 45,000 tonnes between 1952 and 1966. Coffee production increased to about 1.2 million tonnes in the 1980s and has remained more or less consistent since then. East Africa has consistently been the major producer of coffee in SSA with Ethiopia and Uganda as lead coffee producing countries (FAO, 2004c).

The main reasons for increased production of coffee in SSA over the years have been due to increases in the area of harvested coffee and increases in yield due to the availability and use of improved seeds, timely and adequate application of fertilizers and application of appropriate pest control measures.

2.1.4 Harvest and postharvest management

Storage of agricultural products may be done for consumption on a future date or to fetch more money in times of scarcity. Agricultural products can be stored to provide seeds for subsequent planting. Government may also store surplus agricultural products for price stabilization through product release in times of scarcity (Dike, 1994).

Pests and diseases are major limiting factors to successful storage. Several storage insect pests start their infestation in the field and are then carried into the store (Ajayi and Lale, 2001). Timing of harvest has been reported as a cultural method that can be employed in the control of storage insect pests (Olubayo and Port, 1997; Kabeh and Lale, 2004). Crops that are promptly harvested at maturity are less attacked by storage insect pests than those that are left longer in the field after maturity. Prompt harvesting of crops at maturity has been recommended and in practice since the latter half of the 20th century, resulting in better food security.

Losses of up to 30-100% have been recorded on stored food in the absence of efficient insect pest control measures (Caswell, 1984). When grains are not properly dried, they are predisposed to attack by insect pests and diseases. Insect pests and diseases result in a loss of seed viability and modification of the biochemical composition of affected grains (Dike, 2005). The most serious effect of disease infection is the production of mycotoxins in attacked grains. Consumption of such grains may result in disease known as mycotoxicoses (Schilling and Misari, 1992; Marley, 1996). Drying of grains using fire and solar disinfestations has been used in traditional farming systems by resource-poor and small-scale farmers. Storage in air-tight containers, such as metal drums and plastic containers is an old practice, which causes insects to die of asphyxiation (Bailey, 1954). Another common traditional method of postharvest management is the use of ash from cooking fire.

AKST has made available more effective postharvest management measures, which include the integration of storage pest resistant varieties with solar disinfestation and the use of air-tight containers. Chemicals such as aluminum phosphide have been used by large-scale farmers to disinfest crops for storage. The toxic effects of these chemicals demand that they be used judiciously and has also led to the search for alternatives in postharvest management. Oils and powders of plant materials such as neem, eycalyptus, citrus peel, etc., have been found to control postharvest insect pests (Dike and Mshelia, 1997). Several of these plant materials are readily available and are currently in use in postharvest management.

Practicing good postharvest management is needed to keep good quality seed for planting and to secure the harvest, ensuring availability of food and reduction of poverty. In SSA, the use of an integrated approach in postharvest management has not been a common practice, especially among small-scale farmers, mainly due to poverty and lack of education. The training of farmers through farmer field schools, for example, and the provision of soft agricultural loans could go a long way toward improving the technical know-how and financial status of these farmers. Some governments in SSA have in the past and are currently providing agricultural loans to farmers, but these loans are not sufficient to meet demand. Farmer field schools have been supported by FAO and are currently operated in some countries in SSA. Considering economic constraints within SSA, improvements on existing local and traditional knowledge currently available to most resource-poor farmers in the region should be encouraged as a low-cost option for improvements to productivity.

2.1.5 Pest and disease management

Agricultural production in sub-Saharan African agroecosystems is greatly affected by pests such as insects, nematodes, fungi, rodents, birds, weeds, viruses and bacteria. The parasitic weed *Striga hermonthica* commonly known as "witchweed" infests as much as 40 million ha of farmland in SSA and causes losses ranging from 20% to 100% (AATF, 2005).

Over the years, in order to reduce yield losses due to pests and weeds, farmers traditionally have selected well-adapted, stable crop varieties and used cropping systems in which two or more crops are grown in the same field at the same time. They have commonly used wood ash, cattle urine, ground hot pepper and some repulsive plants for insect pest and disease control. Cats were used for rat control as well as flooding or smoking-out of rat tunnels. Practices such as tillage (plowing and hoeing), flooding, digging and burning contribute to pest reduction and cultural measures such as rotations also help to reduce losses. Diverse traditional systems enhance natural enemy abundance and generally keep pest numbers at low levels. Pest management in traditional agriculture is a built-in component in the overall crop production system rather than a separate well-defined activity (Abate et al., 2000).

Modern agriculture has brought the use of herbicides and pesticides. Nevertheless, the majority of African farmers still rely on indigenous pest management approaches, although many government extension programs encourage the use of pesticides. Today, chemicals are mostly used in crops produced in monoculture systems such as bananas, cotton, palm oil, pineapple, rubber and sugar cane and on horticultural crops. The SSA countries importing the highest volumes of pesticides are those with a large, thriving and agrochemical input-intensive export industry, particularly of fresh horticultural produce. These countries include Kenya, South Africa, Zimbabwe and Ivory Coast (Williamson, 2003).

Pesticides have also been used to some extent for combating outbreaks of migratory pests such as locusts. For ages, SSA countries have repeatedly been plagued by locusts such as the African desert locust (*Schistocerca gregaria*). The worst locust plagues in recent times hit the Sahel countries in 1957, 1987, 1993 and 2004. The plague of locusts in 1987 caused particularly severe losses in Mauritania, reaching 60% on pasture lands, 70% on rain-fed crops and 50% on irrigated crops (FAD, 2003). According to initial estimates, in 2004 African desert locusts in the Sahel caused the loss of 2 million tonnes of crops, equivalent to 20% of the population's food needs.

A wide range of regulatory options exists, including outright bans or severe restrictions on chemicals. Legislation and associated regulations comprise an important component of national chemicals management. Appropriate chemicals management requires setting priorities, cooperation and a desire to anticipate and prevent problems rather than simply react to them.

In the mid-1980s, developing countries accounted for about one-fifth of global consumption of pesticides, of which SSA countries accounted for only 4%. Economic and social constraints have kept pesticide use in Africa the lowest in the world. Africa's share has remained around 2% in recent years, with annual pesticide imports fluctuating between US$486-580 million over the period 1995-2000 and with import values estimated at US$503 million in 2000 (FAOSTAT, 2005). The use of pesticides in Africa continues to be extremely low relative to the global pesticide market. With the more recent trends of globalization and trade liberalization, especially in agriculture, the use of these chemicals may be intensified. Although most farmers cannot afford to use chemical pesticides, those who use them often apply wrong doses and use improper procedures. In general, farmers in SSA lack basic agricultural training and this is aggravated by illiteracy that makes it impossible to read or follow complex pesticide label instructions.

Chemicals can contribute to increased food production, as they prevent losses caused by pests, fungi and herbs. Despite their contributions, most chemical pesticides may have created more problems than they solved. The kinds of chemicals used in chemical-intensive agriculture systems have exerted a heavy price, particularly to the environment and human health. Concerns over their harmful effects are of importance due to the fact that most farmers in developing countries are generally unaware of the short- and long-term hazards associated with exposure to many pesticide products (Goldman and Tran, 2002). Pesticide misuse is a big concern in most of SSA. Most sub-Saharan African farmers and farm workers do not use adequate, if any, protective clothing or equipment and their exposure to pesticides is therefore higher than in countries with sophisticated application equipment and strict regulations on pesticides handling (Williamson, 2003). As a result, improper or indiscriminate use of pesticides is a major cause of ill health and environmental damage as well as the source of unacceptably high levels of residues on food or cash crops.

Some of the most hazardous pesticides, as determined by the World Health Organization (WHO), are widely used in SSA. Sixteen such products were documented on the market in Benin in 1999, 25 in Ghana (PAN Africa, 2000) and 45 in Senegal (PAN Africa, 1999). The European Union decided in 1999 to ban imports of Nile perch from countries bordering Lake Victoria in East Africa, after reports of gross and widespread misuse of pesticide to catch fish in the lake (EC, 1999). Many cases of poisoning, including at least 70 deaths in the 2000 cotton-growing season and 24 in the 2001 season (Ton et al., 2000) were reported in Benin. Endosulfan, an organochlorine insecticide (WHO Class II, moderately hazardous), was identified as the cause of most of these cases. Some pesticides are so persistent that they move far and wide, remaining in the environment for decades, and accumulate in fish, animals and humans causing a range of ill effects (PAN Asia and the Pacific, 1999). They may destroy natural predators of pests and disrupt natural immunity in both animals and plants.

Another danger in African countries stems from out-of-date pesticide stocks, in many cases left over from past anti-locust campaigns. Countries generally stockpiled pesticides in order to better prepare for a further invasion. At the end of the 2004 locust plague, for example, Mali was still holding 75,000 liters of pesticide in reserve (Kuiseu and Thiam, 2006), fearing the arrival of further locust plagues. Over 50,000 tonnes of obsolete stocks have accumulated in African countries as well as tens of thousands of tonnes of contaminated soils according to the Africa Stockpiles Programme (ASP). This program was set up to address stockpiled pesticides and Pesticide Action Network (PAN) Africa has played an active part since it began.

Small-scale farmers represent a large proportion of the farming population. Their crop protection strategies such as burning, use of crop diversity, intercropping, use of genetically resistant crop varieties and weed control practices, have recently drawn attention (Hussey, 1990; Kirkby, 1990) and it is now understood that any new research results must fit into a traditional agroecosystem in order to be adopted by farmers (Neuenschwander, 1993). Integrated Pest Management (IPM) involves the integrated use of a range of pest (insect, weed or disease) control strategies in a way that not only reduces pest populations to satisfactory levels but also is sustainable and nonpolluting. Organic agriculture avoids the use of synthetic fertilizers and pesticides. In Ghana IPM was adopted as a major component of agricultural policy in the early 1990s via the Ghana National IPM Program.

The hurdle of adoption has been tackled using participatory methods of extension; one such project was highly successful in allowing farmers to reduce inputs costs, mostly due to reductions in insecticide use, while maintaining and often increasing vegetable yields and incomes. This requirement for farmer training in IPM is reflected in initiatives around the continent for key crops, many based on participatory methods and the farmer field schools.

Biological control has a long history in Africa. Since the early 20th century, South Africa has been a leading world player, particularly in the biological control of weeds, e.g., Opuntia and Harrisia cacti, *Acacia* spp., *Hypericum perforatum*, *Sesbania puniceae*, *Hakea sericea*, *Solanum* spp., *Lantana camara* and many water weeds (*Pistia stratiotes*, *Salvinia molesta*, *Azolla filiculoides*, *Myriophyllum aquaticum*, *Eichhornia crassipes*) (Neuenschwander et al., 2003). An early example of biological control is the control of coffee mealybug (*Phenacoccus kenyae*) following its emergence on Kenyan coffee estates in the 1920s. Correct identification facilitated classical biological control introductions in the late 1930s which, in conjunction with banding, quickly achieved local success. Good country-wide control was achieved by the end of the 1940s. Although use of persistent (chlorinated hydrocarbon) insecticides led to resurgences in the 1950s on estates, smallholder coffee was not affected. While the economic returns to smallholders have never been quantified, estimates in 1959 indicated a £10 million saving for the coffee industry for an expenditure of no more than £30,000 (Greathead, 1967). Cost is often cited as a barrier to biopesticide adoption, particularly in Africa where farm incomes are low and biopesticides have to be imported. A factory for *Bacillus thuringensis* (Bt) in Nairobi, Kenya began production in 2004 and Green Muscle®, a mycopesticide, is being manufactured in Africa. Capacity for biopesticide development and manufacturing is currently limited.

Biological control in IPM involves augmentation or conservation/manipulation of often local—sometimes introduced where they are naturalized—natural enemy populations to make them more effective in suppressing pest populations. An innovative method developed in Africa exploits natural enemies in the IPM context in what has become known as the "push-pull" (www.push-pull.net/) habitat management strategy. Developed for stemborer pests in maize in East Africa, the approach involved using intercrops to modify the behavior of the pest—and its natural enemies. At its simplest, chemicals produced by specific plants planted adjacent to the crop (e.g., molasses grass) attract pest out of the crop; while chemicals produced by specific crops (e.g., the legume *Desmodium*) interplanted with the crop repel pests. The net result is less pest attack on the crop and more parasitism. Following this breakthrough, observations that the parasitic weed *Striga* was suppressed in the presence of *Desmodium* led to the development of a management system for two of the major constraints to maize production in East Africa: cereal stemborers and Striga.

The success of AKST in recent decades has often masked significant externalities affecting both natural capital and human health. Reports of environmental and health problems associated with chemicals have increased, though statistical analyses of such problems are lacking. Legislation can either encourage or discourage the use of natural biological control products, which offer more benign inputs for crop production. Farmers often lack the necessary information to develop better pest management through experimentation. Formal research may be instrumental in providing the input necessary to facilitate participatory technology development such as that done by farmer field schools.

2.1.6 Processing and value addition

Conventional processing is used mainly to reduce postharvest losses and create more convenient products. In processing, a material is transformed from one state to another and its value increases. Value addition is a deliberate operation to produce a totally new and different product. Both conventional processing and value addition approaches make use of science and technology developments.

There are two types of processing: traditional and improved/industrial methods. Traditional processing may be as old as humans. People who lived a life of hunting and gathering smoked and dried meat to preserve it. Fermenting of food staples is a widely used traditional method in West Africa and is still disseminated to communities in other countries. Using biochemistry, physiology, physics and engineering knowledge, traditional methods of processing have been gradually improved upon and have contributed to the development of industrial methods (Asiedu, 1989).

Food security, nutrition improvement and urbanization are among key drivers of food crop processing. Income generation has driven nonfood crop processing and the production of nonfood products from food crops. Food staple crop processing plays a role in reducing post-harvest losses. For example, cassava processed into Gari, flour and chips can be stored or preserved for a longer time than fresh tubers and can be kept during bumper periods to be used for food during lean seasons. About 25% of food grown in the tropics is lost before utilization (Asiedu, 1989). The processing of human food staples and animal feed can lead to value-added wholesome and nutritious foods that can be safely packaged for convenience. Several crops (direct produce or residues) are processed into different types of animal feed with greater nutritional value than individual fodder crops.

Urbanization continues to call for increased and improved processing and value addition in order to obtain food stuff in forms that are convenient to prepare into meals. Foods with shorter cooking/preparation times are less labor-intensive and have extended shelf life. This was exemplified in a shift from local food staples to introduced wheat and rice in West Africa in the late 1970s.

While traditional methods have been used to transform foodstuffs from one state to another, the products are usually not of optimum quality and standards. Inconsistency is common in products from the same or various processors, a problem being addressed gradually with continuous innovation and improved technologies. For example, cassava is processed into different food products in West Africa and into industrial (nonfood) products such as starch and alcohol and flour used in adhesives in many other countries. Traditionally produced flour may vary in color, level of fermentation and be contaminated with dirt. Traditional processing methods have been improved through centrifugation, hot air driers and sieving, thus improving the quality of flour by eliminating fermentation, contamination and coloration.

The influence of AKST in value addition and the utilization of crops is increasing, particularly in the field of biotechnology. For example, AKST has contributed to the improved production of alcohol from cassava. There is still a great need for more innovation in the area of starter cultures for fermented foods, namely, their development, storage and production sustainability. Genetically engineered (GE) microorganisms could also help improve African fermented foods.

Crops widely processed across SSA include cassava, maize, soybean, coffee and groundnuts. Processing of oil palm, coconut palm, cocoa is dominant in West Africa. Processing of sorghum and millet is across SSA but mainly by traditional methods and almost entirely for human consumption. Industrially, but at a small scale, sorghum is processed to malt and opaque beer in South Africa (Asiedu, 1989). In Uganda, a sorghum variety purposively bred for beer production has contributed to the improvement of small-scale farmer livelihoods.

2.2 Livestock and Wildlife Systems in SSA

Livestock are an integral component of strategies for food security and poverty alleviation in SSA through the provision of food (meat, milk, eggs), services (investment for cash in times of need, security against crop failure, manure for soil amendment, draft for tillage and transport, skins and feathers for fiber and religio-cultural functions). Sub-Saharan African livestock comprises 212 million cattle, 163 million sheep, 200 million goats and 21 million pigs (FAOSTAT, 2005). Livestock production is responsible for 20-30% of the agricultural GDP in SSA (Heap, 1994; Abassa, 1995; Lebbie, 1996; ILRI, 2001). Animal products provide high quality protein in human diets as they provide micronutrients, essential amino and fatty acids (Gryseels, 1988; Bender, 1992; Shapiro, 1994; Wilson et al., 2005). Livestock produce manure and urine that contributes to nutrient cycling and maintenance of soil fertility and structure (Murwira et al., 1995; De Haan et al., 1997; Staal et al., 2001; Ndlovu and Mugabe, 2002). Their overall role in environmental sustainability is contested with some researchers maintaining that livestock are detrimental to the environment (Breman, 1995; Dube and Pickup, 2001; Fuhlendorf et al., 2001; Hein, 2006).

2.2.1. Animal genetic resources

Studies in sub-Saharan countries show that livestock performance in terms of meat, milk and egg production has been limited by poor genetic potential and management practices. Efforts to improve livestock productivity, such as importing exotic livestock, crossbreeding and selection, have resulted in limited increases in production. These efforts have had slow momentum since the pre-colonial times to the present era due to a lack of breeding strategies, poor management and inappropriate disease control measures. However, the most important setback was lack of involvement of community stakeholders in breeding schemes, which resulted in poor adoption.

During the pre-colonial and colonial period in sub-Saharan Africa, livestock was kept in various microenvironments characterized by different ecological, social and economic conditions. Traditional management of livestock prevailed, which was mainly pastoralism. In the pre-colonial era, livestock was mainly used for food and cultural practices, such as dowry. Other social activities included feasts, funerals and paying fines. This led to little improvement in livestock productivity, as indigenous livestock were not selected for meat and milk production, but for multiple purposes such as big horns, color and size, to attain desired cultural and social standards. The pre-colonial era included incidences of killer livestock diseases, such as tick borne, trypanosomiasis and Rinderpest, that had little or no treatment and hence ravaged large numbers of livestock. Thus, the presence of large herds and flocks was important as security against diseases but also added to the prestige and status in rural society (Msechu et al., 1987).

During colonial times, when food and cash crops where introduced, agropastoralism started as some of the livestock keepers settled permanently in specific areas. In this era, vaccines and drugs against major livestock diseases were also introduced, thus prompting pastoralists to keep larger herds (Coppock, 1994). The increase in agropastoralism was due to commercialization of both food and cash crops that increased the economic status of most farmers who had solely depended on livestock keeping. In areas where agriculture had not been fully practiced, pastoralism and the nomadic system continued due in part, to the availability of unlimited grazing lands.

During the colonial period, technical efforts were made to improve the genetic potential of indigenous livestock. Some of these attempts included the importation of exotic breeds for crossbreeding and upgrading of indigenous livestock. Attempts were made to select potential indigenous livestock, such as the Sanga cattle in Southern Africa for meat purposes. This was coupled with the introduction of improved managerial practices for exotic and crossbred livestock through improved nutrition and husbandry practices and disease control measures. Much of the work in developing livestock breeds for higher productivity for commercial purposes was undertaken in southern African countries, such as Zimbabwe, South Africa, Nambia and Swaziland (Drucker, 2001).

In East, Central and West African countries, the introduction of exotic cattle such as Friesian, Ayrshire and Jersey led to the first dairy programs in these countries and later to cooperatives. In Kenya, improvement of dairy production was pursued through the importation and pure-breeding of Sahiwal cattle from India and Pakistan. The selected Indo-zebu breeds of cattle were used in areas where the environment was not suitable for the Bos taurus cattle (Das and Mkonyi, 2003). European breeds of wool sheep and dairy goats were also introduced in most of the SSA countries. Much of the livestock development activities in these countries was concentrated on government multiplication and research farms among missionaries and by a few colonial settlers. The impetus for livestock development, though initiated during the colonial era, did not gain much momentum among rural communities in various African countries due to the lack of adequate breeding strategies and the concentration of breeding animals in a few areas such as government farms, the high costs of keeping exotic and crossbred animals and the lack of marketing systems (Coppock, 1994).

The status of animal genetic resources. The domestic animal genetic resources in SSA are mainly indigenous livestock, which have been described as nondescript and have been characterized as having low genetic potential for production traits such as milk, meat and eggs. In recent times, the reduction in number of pastoralists is mainly due to diminished grazing lands as agricultural activities have increased, and land use has shifted to reserves for wildlife and forestry. In general, these types of pressures affect animal genetic resources by decreasing the number of breeds, causing a net loss of breed genetic diversity.

The large number of animal genetic resources is at risk due to factors such as environmental and human preferences. Natural disasters and social insecurity have also been detrimental to the diversity of animal genetic resources. As a result of drought and political instability in Somalia, cattle and small ruminant populations decreased by 70 and 60%, respectively. Such reductions in herd size can significantly affect genetic diversity to the extent of reducing food security and economic well-being of the livestock owners and national economy (Drucker, 2001).

In most of sub-Saharan Africa, where the subsistence level of livestock keeping is practiced, it has been seen that cattle are particularly important for providing food, risk mitigation, draft power, manure and cash income. Goats are second to cattle in importance followed by chickens.

Indigenous breeds of livestock. In sub-Saharan Africa, changes in livestock diversity brought by the introduction of exotic breeds, has led to genetic erosion in various countries due to loss of indigenous breeds or sub-types of livestock. These lost breeds may have had unique genes that cannot be easily replaced in the future. It is well known now that the local breeds constitute an irreplaceable stock of adapted germplasm and should be conserved for both present and future use. The utility of the local breeds should be demonstrated by comparing them with exotic breeds for overall productive efficiency (not merely for short-term milk yield or growth rate) to avoid their elimination through crossbreeding and replacement (Msechu et al., 1987).

Indigenous livestock breeds in sub-Sahara are popular due to low management costs. Many are better adapted to harsh conditions and to some livestock diseases compared to exotic cattle and their crosses. Their attributes include resilience on fragile and marginal land and in drought and stress conditions for longer periods. Selection in pastoralists' herds is usually confined to phenotypic traits of less economic importance, such as color and horn shape. The high value in risk management from cattle is reflected in the fact that 90% of the indigenous cattle are owned by the traditional sector where livestock serve as a bank to be drawn from in times of need. Milk and meat are two important products from cattle. The demand for draft power has been on the increase and some communities keep cattle for draft rather than milk and meat. Cattle are also used to meet several social obligations including dowry and sacrifices. Indigenous livestock, such as cattle and goats, however, are small in size and have low growth rates leading to late maturity and poor milk and meat production (Marples, 1964). In poultry, indigenous chickens have poor egg laying and meat producing performance, compared to exotic breeds. Chickens are also important as a source of quick cash, especially for women and youth, and for traditional festivals and sacrifices. These are kept mostly under free-range or under semi-intensive production systems. The indigenous chickens comprise several strains and are well adapted to the free-range production system under minimum management. The indigenous birds produce 100% of the chicken meat and eggs consumed in the rural areas and 20% of the meat consumed in the urban areas (Das et al., 2003).

Exotic livestock and their crosses. The introduction of temperate livestock genotypes into sub-Saharan Africa has not usually been successful due to their low survival rates or inability to adapt, which had led to low fertility rates. Their performance for meat, milk and egg production is lower than in their countries of origin, due mainly to poor adaptation to the tropical environment and diseases. Some aspects of lower performance can also be attributed to poor management. The introduction of exotic livestock for purebreeding and crossbreeding that started in the colonial period is ongoing (Payne, 1990). Crossbreeding of indigenous livestock for purpose of improvement of both the meat and dairy industries in some SSA countries has grown to successful levels. For example, in Tanzania, the crossbreeding work on livestock started in 1920s with the intention of producing crossbred livestock to meet the demands for milk, meat and eggs. In various countries, the public sector has for many decades been engaged in livestock improvement, multiplication and distribution of improved genetic materials. The efficiency of this system has been hampered by meager funding and has failed to meet demand (mainly centered on ruminant livestock seed multiplication and distribution). The livestock seed supply involved local, purebred exotic cattle, crossbreeds and composite breeds.

With the current free market economy, globalization and anticipated participation of the private sector, exotic breed populations are expected to increase, owing to the fact that most farmers now opt for high yielding animals for marketing purposes. However, indigenous livestock products remain highly preferred by local communities. Improvement in the productivity of indigenous chickens through breeding has been intermittent in sub-Saharan Africa. Earlier efforts were made to cross indigenous strains with exotic British and American poultry breeds of Light Sussex, Rhode Island Red, Black Australop or New Hampshire to improve on size and egg production potential. At present, efforts are being made to identify the different strains of indigenous birds visually and to follow up by comparing their production traits (Das et al., 2003).

Technologies for management of animal genetic resources. In most sub-Saharan African countries, the tools used in the development of domesticated livestock are record-keeping and individual identification for breeding purposes. Use of these tools is limited to state farms and a few small-scale farmers that keep crossbred animals provided by NGOs.

In some government research and multiplication farms, the only breeding technologies used are electronic databases, genetic evaluation software and artificial insemination (Das and Mbaga, 2002). Even these technologies are not widely used, limited to only a few researchers.

Other modern techniques of breeding and conservation of useful livestock genetic resources are in situ and ex situ conservation methods to ensure that each SSA countries have gene banks for useful indigenous animal genetic resources. The DNA technology helps to provide important information concerning the evolutionary history of a breed or species. This can also be a tool for traceability and identification of animal genetic resources. Such modern technologies provide the basis for evaluating breed differences. In recent years, establishment of breeding strategies for development of dairy or meat breeds is through the establishment of Open Nucleus Breeding schemes in various African countries (Nakimbugwe et al., 2004).

Conservation of animal genetic resources. Most SSA livestock breeds will be conserved because of their adaptation and commercial potential. Sub-Saharan African nations would benefit from community-based characterization, conservation and the utilization of indigenous animal genetic resources. Local knowledge and local perceptions of animal breeding and husbandry varies from one community to another. Complementing local and traditional knowledge from pastoralists and agropastoralists with modern AKST can help in attributing economic value to animal genetic resources that should be conserved for future utilization. Resources should include an inventory of valuable traits available in local, adapted as well as in crossbred livestock.

An alternative approach to breeding animals for perceived economic returns and conserving genetic resources is to match genotypes to environments. Instead of importing a genotype and attempting to modify the environment through increased input levels, indigenous breeds could be used and, where appropriate, pre-evaluated with exotic breeds. Lifetime productivity (number of offspring per female), economic returns for the herd or flock (versus individual performance) and biological efficiency (output/input) are some performance indicators. In essence, such a strategy discourages that general recommendations about breeds be made without accounting for the specific environment in which they are expected to perform.

Improving livestock development in sub-Saharan Africa for competition in global markets, both indigenous and crossbred livestock should be considered for commercialization. Assistance should be extended to pastoralists and agropastoralists through extension of advice, research results and credit facilities to commercialize their breeding and management programs. Open Nucleus Breeding Schemes propagate useful traits through the breeding and selection for dairy and meat traits. Some available improved technologies for commercial farmers include improved management strategies such as feedlot systems, fattening practices, embryo transfer and artificial insemination. Techniques for improving grazing practices, storage of fodder, low cost disease control methods and using exotic livestock effectively could improve commercialized livestock development.

2.2.2 Typology of livestock production systems

Variations across regions in terms of climate, animal species, farmer production objectives and other edaphic and biotic factors have led to different livestock production systems in SSA (Jahnke, 1982). Efforts to classify the systems have been based on region (Nestle, 1984), farming systems approach (Wilson, 1995), agroecological zones (Sere and Steinfeld, 1996), natural resource base, dominant livelihoods, degree of crop-livestock integration and scale of operation (Dixon et al., 2001). A proposed comprehensive scheme for classification of global livestock production systems involves quantitative statistical methods based on degree of integration with crops and agroecological zones (Sere and Steinfeld, 1996). In this scheme eleven different systems are identified, of which only eight are represented in any significant extent in SSA. For the purposes of this assessment, these systems are inappropriate as they de-link South Africa from the rest of the southern African region and, being global in nature, they ignore the limited but locally important contribution of landless systems to decreased hunger and poverty in SSA. Another method described 17 farming systems in SSA, of which 12 include livestock (Dixon et al., 2001). Detailed classification systems can mask the generic policy issues that are common in SSA livestock production, allowed for in more broad-based systems (Devendra et al., 2005).

Production systems below are summarized into four main categories: pastoralism (also called range-based systems (Devendra et al., 2005), agropastoralism, mixed crop-based and landless or industrial (Sere and Steinfeld, 1996; LEAD, 2003). Wildlife is discussed within each system as appropriate and differences due to eco-geographic SSA regional groupings are highlighted in each system.

Pastoralism. This system has been in existence in SSA for over three thousand years and is characterised by a mixture of livestock species, including wildlife, kept for multiple purposes. Pastoral systems are found mainly in arid and semi-arid areas in SSA and limited areas in the subhumid zones in East Africa and West Africa (Sandford, 1983; Wilson et al., 1983; Swift, 1988). Pastoral systems are defined as those in which more than 90% of feed eaten by livestock comes from the range and over 50% of gross household revenue comes from livestock or livestock-related activities (Devendra et al., 2005). The major livestock species found in these systems are cattle, donkeys, goats and sheep in central and southern Africa with the addition of camels in East and West Africa. The livestock are mostly of indigenous breeds that are adapted to the climatic conditions of these areas and are tolerant to prevalent diseases (Ruthenberg, 1980; Sere and Steinfeld, 1996) but their productivity per unit land and per animal unit is low (FAOSTAT, 2005).

Pastoralists make use of marginal areas in terms of cropping potential (low and variable rainfall, very hot climate, etc.) and mobility is a major characteristic of these systems. Range management has traditionally been based on moving livestock to follow quality and quantity of feed with flexible stocking rates but strong cultural norms on where and when to graze. Consequently water availability is a strong driver of animal populations and their distribution at the landscape scale.

The major livestock products in this system are milk for local consumption with excess being sold to neighbors and very little processed to butter or sour milk (Wilson, 1995). Sale of livestock is a recent post-colonial phenomenon comprised mainly of small ruminants that are normally slaughtered except in times of drought, when cattle are sold to destock the herd. Wildlife are important as a source of bush meat, especially in Central and West Africa (Asibey and Child, 1990; Ntiamoa-Baidu, 1997; Thibault and Blaney, 2003) and as a source of income through tourism, especially in East and Southern Africa (Humavindu and Barnes, 2003; Reilly et al., 2003; Phutego and Chanda, 2004).

Wildlife competes with livestock for range resources in these systems (Prins, 1992; Skonhoft, 1998; Skonhoft and Solstad, 1998). The advent of colonialization and the subsequent creation of independent states have instituted formal laws that control the use of range, usually by reserving large tracts of land for wildlife to the detriment of pastoralists and their livestock (Prins, 1992; Blench, 2001). Policies allowing for flexible land tenure systems and diversification of pastoral livelihoods would help the sustainability of this system.

It is generally agreed that this system of livestock production today faces challenges from increasing population pressure that impede the movement of trekking livestock in pursuit of feed and water, the expansion of cropping land into pastoral lands and the need for increased productivity to supply goods and services to growing populations. While earlier perceptions of policy makers and external donors was that the system is inefficient, current knowledge has shown that the flexible opportunistic management strategies used by pastoralists are sensible, highly productive and environmentally sustainable (Behnke et al., 1993; Reid and Ellis, 1995; Scoones, 1995; Swift, 1996). The challenge for AKST is to bring new technologies such as satellite imagery and quantitative modeling processes to provide further insights into productivity patterns of the system and offer policy options that ensure that the system can continue to contribute to the overarching goals of this assessment.

Agropastoral system. This system is found in the semiarid, subhumid and humid tropics and in tropical highland areas (Sere and Steinfeld, 1996). Livestock are dependent on natural forage and cropping is important but there is low integration with livestock. Livestock migration at certain times of the year is common (Devendra et al., 2005). The major livestock species are cattle, goats, sheep, poultry and, where religious and cultural beliefs allow, pigs. Wildlife is abundant in this system, sometimes leading to conflicts with people and livestock (Prins, 1992; Barnes et al., 1996; Skonhoft, 1998; Blom et al., 2004; Bassett, 2005; Ogutu et al., 2005).

Livestock productivity is higher than in the pastoral system but still insufficient to meet the needs of the growing population in SSA. The main products are meat, milk, skins, manure and draft power plus sociocultural services. In areas close to urban centers, meat, milk and skins are processed for sale to urban dwellers. This is particularly well developed in densely inhabited areas of East and southern Africa for meat where cold storage facilities allow for longer term storage. In other countries sales at specific religious periods ensures sustainable incomes to livestock owners (e.g., Ethiopia and Nigeria). Drought is a major threat in this system as it results in crop failure and massive sales of livestock (asset attrition). The challenge for AKST is developing reliable early warning systems to avert catastrophic effects of droughts and designing livestock management systems that alleviate shortages during dry season grazing.

The dominant source of feed is the range and its management has been a top priority in terms of legislation and policies in East Africa and Southern Africa. The conventional wisdom has been that agropastoral systems of SSA are overstocked and policies have targeted population reduction (Hardin, 1968; Behnke et al., 1993). The concept assumes that a rangeland has a stable state vegetation mix which is destabilized by grazing and as long as the destabilization is not excessive the range will return to its steady state vegetation. If grazing is excessive then the range loses some of its vegetation species and performs below potential reflected in reduced animal productivity. This view is countered by the assertion that in dry environments the long-run primary productivity of the range is influenced more by rainfall (and other abiotic factors) than by intensity of grazing by livestock or wildlife (Ellis and Swift, 1988; Scoones, 1989, 1992; Behnke et al., 1993).

This dynamic has led to the notion of nonequilibrium ecosystems that are better managed through flexible and opportunistic strategies that allow overstocking during wet seasons and destocking during dry seasons, or the provision of externally sourced supplementary feed during these periods, when massive stock losses occur through death due to starvation (Behnke et al., 1993). AKST has contributed to the changing perception of rangeland management in dry areas of SSA. There are divergent views on this as other researchers have found the impact of livestock to be critical (Briske et al., 2003). However new range management strategies that integrate local knowledge and involve active participation of local communities could be the answer to the issue of whether these systems are sustainable in perpetuity and at what stocking rate they would collapse, if ever. The use of AKST from all sources in the evolution of such systems might be beneficial in the long term.

Mixed crop-based systems. These systems are the most important livestock production systems in SSA in terms of animal to people ratio and animal productivity per unit of land (Sere and Steinfeld, 1996) and form the backbone of smallholder agriculture (Devendra et al., 2005). The systems predominate in humid and sub-humid agroecological zones but they are also found in arid and semiarid tropics and the tropical highlands of East and West Africa. The systems can combine livestock with either annual or perennial crops though the latter is limited in SSA and they exist both in irrigated and rain-fed areas. Ruminant animals graze native pastures and use crop residues as additional feed sources after harvest, whereas nonruminants depend on crop by-products and household kitchen wastes.

The main livestock species kept in these systems are cattle, sheep, goats, donkeys, poultry and pigs. The integration of livestock and crop production is an integral component of these systems and allows for efficient use of labor and other resources (Wilson et al., 1983; Devendra et al., 2005). Livestock provide traction for plowing, transportation of produce and processing of produce plus manure for soil fertility and use crop residues as feeds. Farmers who use animal draft power for cropping operations improved the quality and timeliness of farming operations, have increased crop yields and incomes and cultivated more land (Wilson, 2003). Livestock contribute to the environment and its conservation through the provision of manure which can assist in sustainable nutrient cycling and in improving soil structure and fertility. It has been argued, however, that livestock merely transfer nutrients from the range and concentrate them in cropping areas and this could be detrimental to the range (De Leeuw et al., 1995).

In addition to the environmental and cropping advantages discussed above, livestock contribute to reduction in hunger as food sources (meat, milk and eggs). The crop-based livestock systems provide a least-cost, labor-efficient way of increasing these outputs (Devendra et al., 2005).

Landless systems. These are defined as systems in which less than ten percent of the dry matter consumed by livestock is produced on the farm (Sere and Steinfeld, 1996) and the systems are further divided into ruminant and monogastric systems or rural and urban systems. The ruminant systems are often based on zero grazing with the increase use of purchased forages or hired land with forage or leguminous trees to harvest leaves (Devendra et al., 2005) or grazing limited to roadsides. Small ruminants (especially sheep in Ethiopia and Nigeria) predominate in these systems although dairy production is practiced in Lesotho, Kenya and Ethiopia. The monogastric systems in SSA are mainly poultry systems, unlike in South Asia where pigs are the major livestock. Urban and periurban livestock production systems involve pigs, poultry, dairy cattle and, where by-laws permit, feedlot fattening. The scale and intensity of production are determined by market opportunities, food preferences and availability of space.

The productivity of these commercial enterprises is high (Sere and Steinfeld, 1996; Delgado et al., 1999; Spencer et al., 2004; Devendra et al., 2005), but their land area is limited. Though current and projected productivity levels lag behind world averages (FAOSTAT, 2005), there is potential to increase productivity per animal unit in SSA through improved genetic resources and disease management and eradication, including gene-based technologies (Makkar and Viljoen, 2005).

On the downside are the potential environmental and human health hazards posed by these urban and periurban systems (UNDP, 1996; Delgado et al., 1999; Devendra et al., 2005), especially where laws and by-laws regulating livestock production are weak or nonexistent. This presents an opportunity for AKST to provide policy options and goods and services to avert the risks posed by these systems.

2.2.3 Trends in productivity, processing, marketing and value addition

Livestock in SSA are kept for multiple purposes and their products can be classified into immediate, intermediate and indeterminate (Wilson et al., 2005). The immediate products include meat, milk, eggs, fiber, hides, skins and feathers while intermediate products are draft power and manure (as fertilizer and as fuel). The are intangible values attributed to livestock, based on indeterminate products, which include hedging against crop failure (risk reduction), serving as an investment portfolio, sociocultural and religious roles, as well as sport and recreation functions.

Livestock and wildlife are important to SSA country economies. For example, the livestock subsector is responsible for over 30% of the agricultural gross domestic product (GDP) and more than 50% of agricultural labor. The wildlife sector, on the other hand, is worth US$7 million with an annual growth rate of 5% (Wambwa, 2003). The productivity of SSA livestock in terms of immediate products is low in comparison to world averages and projected to remain so for the next 20 or so years (Table 2-1) unless there are major technological and policy interventions. Beef production is 20 times less while milk production is about 40 times less than world averages and pig and poultry products do not fare any better.

The protein consumption from livestock in SSA has remained low, with an average of 9 kg meat and 23 kg milk per person per year, compared to the developed countries, with an average of 76 kg and 145 kg respectively (Delgado et al., 1999). In some SSA countries the proportion of wild meat in total protein supplies can be high thus complementing livestock protein, however, wildlife consumption is often unrecorded and therefore underestimated (Asibey and Child, 1990).

The increase in population and urbanization, however, has resulted in an increased demand for livestock products (Delgado et al., 1999; ILRI, 2001; Owen, 2005). The huge production deficit is currently met through imports of animal products (FAOSTAT, 2003; ILRI, 2003; Owen, 2005). Interventions in animal breeding and genetics, nutrition and health and policy options for management of grazing and land tenure systems are needed to increase productivity levels in SSA, so as to take advantage of income potentials from the increased demand for livestock products.

In SSA edible livestock products are generally marketed in an unprocessed form. Milk is a perishable product and needs to be processed within a few hours from milking to prolong shelf life and marketability. Several traditional and modern processes exist for the processing of milk (Brumby and Gryseels, 1985). Most of the milk produced in SSA is marketed raw or with minimum rudimentary processing within the community. Meat is often sold fresh and there are very few canning and other processing plants outside of Southern Africa. The market for live animals is quite large, especially during religious festivities. This lack of value-addition provides a potential for AKST to contribute to increased income earnings and hunger reduction through technologies and systems that increase processing of these livestock products for increased shelf life, ease of transportation and diversification of products on sale to consumers and ultimately, wealth creation.

2.2.4 Livestock and wildlife pests and diseases

Pests and the diseases they transmit are major constraints to the development of livestock and wildlife industries in SSA (Bengis et al., 2002). Hence one step toward develop-

Table 2-1. *Livestock production (million tonnes) past and projected.*

Product	World		Sub-Saharan Africa	
Year	1967/1969	2030	1969-1999	2015-2030
	Million tonnes			
Bovine meat	38.0	88.4	1.5	3.0
Ovine meat	6.6	20.1	2.8	3.0
Pig meat	34.1	124.5	n/a	n/a
Poultry meat	12.9	143.3	3.8	5.1
Milk	387	874	2.7	2.8
Eggs	18.7	89.9	3.7	4.1

Source: Bruinsma, 2003.

ing these industries is appropriate control of livestock and wildlife pests and diseases.

2.2.4.1 The livestock/wildlife interface in sub-Saharan Africa

In most of SSA livestock and wildlife share similar habitats and hence, at times compete for resources. This coexistence has never been easy and there has been a long-standing conflict between livestock owners and animal health authorities on the one hand and, wildlife conservationists on the other. This conflict is largely based on differing attitudes towards control of livestock diseases associated with wildlife. Livestock and wildlife disease problems are frequently bi-directional at the livestock/wildlife interface and the situation becomes more complex when humans are involved. Livestock and wildlife diseases can be grouped into three different categories as follows:

1. Infectious diseases associated with wildlife known to cause diseases in domestic livestock. The single most important factor responsible for causing an outbreak of any of these diseases is probably the direct or indirect (vector) contact of infected wild hosts or populations with susceptible domestic animals at the interface of their ranges, where mixing has occurred on common rangeland, or, where other resources, like water are shared. Diseases in this category include foot and mouth disease (FMD), African swine fever (ASF) and classical swine fever (hog cholera), trypanosomiasis, theileriosis or corridor diseases, African horse sickness, Rift Valley fever (RVF), bluetongue, lumpy skin diseases, malignant catarrhal fever and Newcastle disease (Bengis et al., 2002).
2. Multispecies diseases that affect both livestock and wildlife. Transmission of these diseases can occur in both directions, although in certain regions, dominant role players have been identified. These diseases are generally fatal to both wildlife and livestock and are frequently zoonotic. Examples of such disease are anthrax, rabies and brucellosis (Bengis et al., 2002).
3. Alien diseases that infect wildlife and domestic livestock. Some of the best examples in this category are certain diseases historically alien to SSA, which were probably introduced into the African continent with the importation of domestic livestock from Europe and Asia during the colonial era. Indigenous African free-ranging mammals are generally susceptible to these foreign agents and significant morbidity and mortality may be encountered in both wildlife and domestic livestock. Such diseases include rinderpest, canine distemper, bovine tuberculosis, African horse sickness and African swine fever (Bengis et al., 2002).

2.2.4.2 Selected diseases and pests of livestock and wildlife

Rinderpest. Rinderpest is a viral disease introduced into Eritrea from India during the pre-colonial era either by the Italian army in 1887/1888, or by a German military expedition that brought infected cattle from Aden and Bombay to the East African coast. The disease killed more than 90% of all cattle population and wildlife (Henning, 1956). However, during this pre-colonial era, even without advanced technology, cattle farmers in South Africa managed to contain rinderpest through immunization of cattle, by using the bile of animals that died of the disease and, by end of 1898, the disease was under control and temporarily disappeared from South Africa. The disease resurfaced again in 1901 because cattle immunization against rinderpest was limited to South Africa and because SSA lacked strict border control (Henning, 1956). The situation remained unchanged during the colonial period, making rinderpest one of the most devastating diseases of both livestock and wildlife. Advances in AKST have created efficient vaccines to contain rinderpest and, currently, the disease is no longer a threat. Globalization has also played an important role and now, under the global rinderpest eradication program (GREP), a total of 25 SSA countries have managed to declare themselves or zones within their country free from this disease. In addition, six SSA countries have been declared rinderpest-free by the World Organization for Animal Health (OIE) (OIE, 2007).

The eradication of rinderpest (not only in some SSA countries, but in most western and Asian countries) has been made possible through effective vaccination and modern diagnostic techniques. Although rinderpest is a disease of both domestic livestock and wildlife, it is now known that infection is from cattle to wildlife and not vice versa. This means that elimination of the disease in domestic livestock leads finally to eradication in wildlife and finally from all animals in a specified area (OIE, 2007). It should be noted that viral diseases are easy to eradicate once an effective vaccine has been identified and appropriate vaccination programs are in place. The question is whether or not the rinderpest control/eradication strategy can be applied to other livestock and diseases.

Theileriosis. Theileriosis of cattle in Africa, particularly East Coast Fever (ECF), caused by *Theileria parva* protozoa and transmitted by *Rhipicephalus appendiculatus* ticks has undoubtedly had more impact on the development of the cattle industry, veterinary infrastructure, legislation and policies and veterinary research than any other livestock disease complex in Africa. Theileriosis affects both cattle and buffalo and it is now generally accepted that *Theileria parva parva* is a cattle-adapted variant of *Theileria parva lawrenci* in buffalo. Infection in buffalo is generally dormant, but in cattle it causes very high mortality rates, making cattle farming in the presence of buffalo and a suitable vector a hazardous undertaking (Norval et al., 1992).

Theileriosis was first recognized in Southern Africa during the colonial period, when it was introduced at the beginning of the century with cattle imported from eastern Africa, where the disease has been endemic for centuries. Although the disease was eradicated from most southern African countries, it has persisted in eastern Africa and, it has expanded in recent years, particularly at the periphery of its distribution in Sudan and Zambia (Henning, 1956).

During the colonial era, cases of ECF were treated by inoculation of susceptible cattle with blood from a sick or recovered animal. Although this method worked in some cases, its effect on overall disease control was limited (Henning, 1956). Different communities in SSA have practiced traditional veterinary medicine in the treatment of ECF since pre-colonial times and, some of the remedies have been quite effective (Bizimana, 1994; Minja, 1994; Sindiga et al., 1995; Kambewa et al., 1997; Wanyama, 1997; Dery et al., 1999; Minja and Allport, 2001). The colonists introduced dipping schemes in early 1900, whereby cattle were dipped in acaricides to control the vector ticks, a practice which proved to be quite effective and has been in use up to now.

Although dipping can fully control ticks if applied appropriately, the method has been unpopular lately due to many factors, namely, the development of tick resistance to the acaricides in use, pollution to the environment, presence of alternative hosts and the ever rising costs of acaricides. Effective vaccines have been developed, both against the tick and the parasite (Jacobsen, 1991; Willadsen, 2002). Breeding of tick resistant cattle is another development that has been introduced to combat tick-borne diseases (TBD), particularly ECF (de Castro and Newson, 1993). However, it has now been appreciated that integrated control of ticks and tick-borne diseases is the only viable way of combating tick-borne diseases. In this approach, the different methods are used in combination, to achieve maximum results with minimum environmental effects (FAO, 1998). Unlike rinderpest, eradication of theileriosis has not been easy. While an effective vaccine for rinderpest, which is a viral disease, has been found, parasitic vaccines are more difficult to make and, normally, are less effective. In addition, both the tick vector and the disease are shared by wildlife and livestock and control in wildlife is not possible (Norval et al., 1992). Efforts have therefore been directed at reasonable control, rather than eradication of theileriosis.

Trypanosomiasis. Trypanosomiasis is a vector-borne zoonotic disease affecting wildlife, domestic livestock and humans. The disease in animals is called nagana, while in humans it is sleeping sickness. It is caused by the protozoa Trypanosoma and transmitted by tsetse flies of the genus *Glossina*. Trypanosomiasis profoundly limits the development of the livestock industry. Many species of antelope, buffalo, warthog, hippopotamus, elephant and rhinoceros are capable of surviving in tsetse fly belts and frequently have significant infection rates with various Trypanosoma species, thus serving as excellent maintenance hosts for nagana (Morrison et al., 1981).There are 37 tsetse-infested countries in SSA; of the 212 million cattle in this region only a small percentage are located in tsetse-infested areas (which unfortunately are the fertile areas), whereas the remainder are distributed on the periphery (Hursey and Slingenbergh, 1995).

Trypanosomiasis and its vector the tsetse fly are indigenous to SSA and local farmers have practiced traditional veterinary medicine to control both the vector and the disease in livestock since pre-colonial times (Bizimana, 1994; Minja, 1994; Sindiga et al., 1995; Kambewa et al., 1997; Wanyama, 1997; Dery et al., 1999; Minja and Allport, 2001). The earlier colonialists who came to tsetse infested areas in SSA were highly affected by trypanosomiasis and suffered from sleeping sickness.

During the colonial era, methods introduced to control tsetse flies were rather undesirable, including the elimination of all game, cutting down of trees favored by tsetse flies and later use of chemicals by aerial spraying. With advances in AKST, more modern techniques were introduced, based on control of the vector by dipping cattle in insecticides to kill any flies that would land on treated cattle, use of traps and impregnated targets to catch tsetse flies and trypanocidal drugs to treat or prevent infection in animals. Trypanotolerant cattle, like the N'Dama of West Africa have also been identified and efforts are being made to propagate them for use in tsetse-infested areas (Paling and Dwinger, 1993).

African governments developed a new initiative, known as the Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC), which seeks to employ an area-wide approach and appropriate fly suppression methods to eradicate tsetse and, ultimately, create tsetse-free zones (Kabayo, 2002). Efforts have also been made at the international level—Program against African Trypanosomiasis (PAAT). PAAT, officially established in 1997, forms the umbrella for an inter-agency alliance comprised of FAO, IAEA, AU/IBAR, WHO, research institutions, field programs, NGOs and donors. PAAT treats the tsetse/trypanosomiasis problem as an integral part of development and poverty alleviation in order to achieve positive and lasting results in trypanosomiasis-affected areas. The overall goal is to improve the livelihood of rural people in the tsetse-affected countries of SSA (http://www.fao.org/aga/againfo/programmes/en/paat/about/html).

Like other parasitic diseases, control/eradication of tsetse flies or trypanosomiasis is a difficult, if not impossible task. The snags encountered in making an effective parasitic vaccine, the widespread distribution of the vectors and the presence of so many alternative wild hosts make it a painful and nearly impossible venture. However, efforts need to be made to reduce the impact of tsetse and trypanosomiasis to at least economically acceptable levels.

Bovine tuberculosis. At the livestock/wildlife/human interface, M. bovis infection is of particular importance in SSA because of recent initiatives to establish transfrontier conservation areas. The African buffalo (*Syncerus caffer*), as maintenance host, plays a major role in the spread of infection to wild animal species including lion, leopard, warthog, kudu and baboon and also poses a distinct risk of infection to cattle and their owners.

In Africa, bovine tuberculosis was most probably introduced with imported dairy and *Bos taurus* type beef cattle during the colonial era. This disease is now widespread and prevalent in 80% of the African member countries of the World Organisation for Animal Health (OIE). Bovine species are natural hosts to the disease, but a wide spectrum of domestic and wild animals, as well as man can be infected (Ayele et al., 2004).

Effective control and eradication of bovine TB can be achieved through conventional procedures of test and removal (slaughter), under mandatory national bovine TB programs. While the procedure has worked successfully in developed countries, control and eradication has not been achieved in SSA because member countries cannot afford the control program and compensation for slaughtered animals. The presence of wildlife reservoirs also makes bovine TB control even more difficult (Ayele et al., 2004). Strategic vaccination of susceptible domestic animals in endemic areas is a feasible option for Africa, where control of bovine TB is a much more acceptable and practical measure than eradication (Daborn et al., 1996).

Advancements in AKST have resulted in the development of molecular biological techniques, like DNA sequencing, for efficient detection and differentiation of M. bovis isolates, to enable effective control. Unfortunately, widespread adoption of the method in SSA has been curtailed by issues such as potential costs and difficulties in technology transfer (Ayele et al., 2004).

Newcastle disease. Newcastle disease (ND) is a viral infectious disease of poultry and a major constraint to the village poultry sector in Africa. The village poultry sector has evolved to be robust and sustainable and is a source of dependable income in most countries in SSA (Alders and Spradbrow, 1999). Since pre-colonial times, traditional veterinary medicine has been practiced to treat ND (Bizimana, 1994; Kambewa et al., 1997). During the colonial era, commercial poultry farming was introduced. The introduction of commercial poultry farming resulted in the introduction of previously nonexistent poultry diseases. This era therefore saw the introduction of new drugs and vaccines to control the emerging diseases (Sakaguchi et al., 1996). Due to the important role of local chickens for local people, the control of ND remains an important issue. An effective, affordable and thermostable vaccine (I2 vaccine), has been developed to control ND in indigenous chicken. This vaccine has revolutionalized rural poultry keeping and raised the socioeconomic status of poultry farmers in several SSA countries (Wambura et al., 2000; Riise et al., 2005). If the I2 vaccine is introduced to all rural poultry farmers, the socioeconomic status, particularly of women and children, who in most cases are owners of indigenous chickens, would be improved.

Importance of wildlife and livestock diseases control on poverty alleviation, food security and improved nutrition. The population of SSA is growing. Between 1975 and 2005, it more than doubled from 335 to 750 million people and is projected to increase to 1100-1200 million by 2025 (UNFPA, 2007). With such a large population and diminishing resources, the importance of food security in SSA cannot be overemphasized. Apart from the artificial boundaries created by colonialists, most countries in SSA within similar agroecological zones share similar climatic conditions. Such countries therefore have similar livestock and wildlife species and, hence, similar pests and diseases. Improved livestock and wildlife industries can work to ensure sustainable food security and improved socioeconomic status, particularly of the resource-poor farmers in SSA, through holistic and regional pest and disease control strategies.

2.3 Forestry, Agroforestry and Forest Products

2.3.1 Forest genetic resource management and biodiversity potential

Natural forests are being cleared (deforested) while the extent of plantation forests is increasing (FAO, 2007). In 2000, total world forest resources were estimated to be 3.8 billion ha with forests in Africa comprising 650 million ha (MA, 2005). Globally, forests comprised about 30% of the world's land area in 2007 (FAO, 2007). According to current estimates, 9.4 million ha of world forests are converted to other land uses (i.e., deforested) every year in the 1990s (FAO, 2001; UNHCR, 2004; MA, 2005). Tropical forests cover less than 10% of earth's land surface yet contain at least 50% of all species, with the Amazon Basin having the richest biota on Earth (Ervin, 1988; Myers, 1988; MA, 2005). Tropical forests are being depleted faster than any other ecological zone and the loss of biodiversity has been well documented. Some have claimed that the earth is in the opening stages of an extinction crisis (Raup and Sepkosky, 1984; Myers, 1986; Raven, 1987; Wilson, 1988). Net annual forest losses are calculated between 7.3 and 9.4 million ha^{-1}, with the African continent contributing close to 50% of these losses (MA, 2005; FAO, 2007).

Human-induced deforestation of tropical forests increases every year, with a subsequent increase in poverty. Rapid population growth from immigration among communities of small-scale cultivators, displacement due to conflicts/wars, shifting cultivation, agricultural practices, bush fires, illegal logging, urbanization, etc., are strongly and adversely affecting the integrity of forest ecosystems (UNHCR, 2005). SSA's remnant bloc of the relict species of the tropical forest within the Congo Basin is under intensive exploitation, mainly due to extraction for timber, especially in Cameroon, Gabon, Congo-Brazzaville, Central African Republic and the D.R. Congo and to human activities such as shifting small-scale agriculture.

Today, agriculture and the forest sector are more inextricably linked than ever before and as they face similar challenges in coping with poverty and food insecurity. In SSA, shifting agriculture clears areas of the forest with fire and destroys surrounding non-cleared zones where species such as *Chromolaena odorata* quickly establish and prevent forest regeneration. The sustainable management of forests and trees, including the use of agroforestry and watershed/wetland management, is an integral part of the effort to reduce food insecurity, alleviate poverty and improve environmental quality for the rural poor.

Technological innovations and new management methods that increase agricultural/forest yields per hectare can also have a significant positive impact on the world's forests. For example, a National Geographic Society supported study on Imbongo's vestigial and gallery forests (D.R. Congo) in 2002 showed that poor rural communities were destroying these forest ecosystems because of poor agricultural markets and market instability. A 50 kg-bag of cassava (manioc), for example, costs US$3-5 in Imbongo but the same product in Kinshasa is sold for US$40-50 depending on the season. This unbalanced market keeps the producer in permanent social insecurity and poverty and forces the peasant to produce more with inappropriate tools and methods. Of course, this scenario increases the pressure on forests/wetlands, maintains poverty levels and decreases natural regeneration time, resulting in degradation of forest resources. Another reason of agriculture impact on forests relates to export policies, linked to a high demand from Asian countries notably and from some European countries.

In the SSA region, forests are under various physiognomy, from humid tropical jungles of the Congo Basin to woody drylands of West and East Africa including the Miombo forest of Southern Africa. The situation of forest ecosystem health and integrity is worsening due to poor agricultural practices, increased use of biomass for cooking, especially around big cities, abusive bush fires and illegal logging. The integration of AKST in forest management and conservation in the SSA region is much needed and currently diluted.

Agroforestry practices are sparsely introduced and poorly coordinated. The budget allocated to forestry/agroforestry by states is generally less than 1% of the GDP. However, countries such as South Africa, Nigeria, Ghana, Côte d'Ivoire, Kenya, etc., are working hard to improve, while other countries such D.R. Congo, Gabon, Cameroon, Congo-Brazzaville, etc., are still relying on seasonal gathering of forest products, therefore increasing the poverty among communities.

Agroforestry can help to reduce pressures for clearing through the production of timber, nontimber forestry products (Leakey et al., 2005) and fuelwood from trees on farmland, thereby reducing the need for cutting from natural forests. Agroforestry also promotes the sustainable use of farmland, thereby reducing the pressure of forests on agricultural production (Van Noordwijk et al., 2004). Agroforestry can be considered as a means to reduce pressure on forest margins, forest reserves and national parks. Indeed, by providing timber, fuelwood and other forest products on farms, the needs for illegal cutting will be reduced. This is true in theory, but in practice, there are still some constraints. One of these constraints is related to the nature of logged versus planted trees. For example, in the D.R. Congo, *Eucalyptus* and *Acacia* trees have been promoted for reforestation while *Terminalia superba* and *Milittia excelsa* are cut.

The World Agroforestry Centre in Nairobi has been at the forefront of research in agroforestry but, as evidenced by the bulk of their publications in English only, seems to be Anglophone-oriented. Therefore the tremendous research annual output and resources generated there are not well disseminated within the SSA region.

2.3.2 Pest and disease management

In the SSA region, deforestation is generating the degradation of habitat and the reduction of biodiversity. Regeneration is disturbed by alien species with adverse impacts on the soil. For example, the bioinvasion of cleared forests by the weed named *Chromolaena odorata* in the Congo basin is a real threat for gallery forests where shifting agriculture is practiced. Vestigial forests with relict species in the Congo Basin are degrading under the pressure of refugees (UNHCR, 2005).

2.3.3 Quality of produce and productivity

Forests provide various products and raw materials. Most of these resources are renewable. Currently the time to plant maturity is longer than the exploitation rate. This means that when forest resources are over-exploited, regeneration times shorten. This is a key issue to be solved in order to promote the sustainable use of forests. In the SSA region the productivity of forests is low and decreasing annually due to abusive bush fires, shifting agriculture practices and invasive immigration related to conflicts. This picture means that forests are going to be endangered ecosystems in the very near future if poverty is not alleviated. Agroforestry can be part of a solution if researchers and other scientists would work in partnership with communities. A strong constraining factor that does not allow the integration of AKST in forestry management policy relates to information dissemination and local participation. Promotion of a forest industry within the SSA region is also limited.

A recent development is the promotion of agroforestry tree products (AFTPs) (Simons and Leakey, 2004). AFTPs are timber and nontimber products sourced from trees cultivated outside forests. These products include fruits and nuts, pharmaceutical products and industrial products such as gum and pectin. Their quality is variable (Leakey et al., 2005) and they require specific quality control. The World Agroforestry Centre has done considerable research on AFTPs and their marketability (Maghembe et al., 1998; Leakey and Tchoundjeu, 2001; Leakey et al., 2005).

2.3.4 Timing of harvest and postharvest management

Timing of harvest/postharvest management, including processing and the quality of products, value-addition, etc., or simply forest ecosystem management strategies require scientific knowledge. Science and technology outputs generally are not consumed by forest users. If current weaknesses in forest science and technology efforts persist, the gap between developed and developing countries in the adoption of sustainable forest management practices could grow. Limited application of scientific advances to a few elite segments of the forest sector will contrast sharply with the lag in the rest of the sector resulting from insufficient research and development efforts, especially in the management of indigenous forests and those catering to local needs. The narrow pursuit of commercial profits could increase society's vulnerability to unforeseen environmental and socioeconomic changes.

There is an urgent need to strengthen scientific capacity, especially in countries where it remains poor such as in the Congo Basin countries. The signed statutes establishing the Conference of Ministers in charge of Forests in Central Africa (COMIFAC), in 2002, is an important step towards transboundary management policies of forests for sustainable development. Common views, common goals and joint efforts can lead to shared benefits within the subregion (FAO, 2003b).

2.3.5 Processing, value addition and utilization

Forests are stocks of raw materials. Africa brings the highest proportion (58%) of non-value added forest products into world markets. This means that SSA is mainly supplying the raw materials and that its forest industry remains poor. For example, despite the availability of forests in the SSA, most consumed paper is imported (only 2.2% is value-added) (FAO, 2005b).

2.4 Fisheries and Aquaculture

2.4.1 Fish species and other aquatic species from fisheries and aquaculture

It has been estimated that about 210 million people in SSA, constituting about 30% of the population, are food insecure and this number is expected to rise (FAO, 2003a). Many poor in SSA are dependent on marine and inland capture fisheries and fish from aquaculture for their protein requirement and livelihoods. Fish protein constitutes about 22% of overall animal protein and per capita fish consumption is barely 6.7 kg per person a year, less than the average of the developing world (FAO, 2003a). Rural fishing communities generally have a higher percentage of people living below the poverty line than the national average (Whittingham et al., 2003). The high rate of poverty in rural fishing communities results in intensification of individual fishing efforts and subsequent overcapitalization and overexploitation of capture fisheries.

About 10 million people in SSA make their living as fishers. The majority are small-scale fishers, fish processors and traders. There are far more fishers than what many small-scale fisheries can sustain. As a result, catch levels are generally above their maximum sustainable yield levels. Moreover, overfishing further exacerbates the loss of economic rent from the fishery, increases poverty and the loss of livelihoods and decreases food security (Fisheries Opportunities Assessment, 2006).

Demand for fish as food and feed doubled between the 1970s and 1990s, with the developing world responsible for over 90% of this growth. The production of food fish from capture in SSA was 2.1 million tonnes in 1973 and 3.7 million tonnes in 1997 while the production from aquaculture was 11.7 million tonnes in 1997 (FAO, 2000a). This production represented a 4% share of the world's total in 1997 and projections to 2020 bring this share to 5%. The production of molluscs from aquaculture in the SSA region is nil (FAO, 2000a), while only 3,000 tonnes of crustaceans were produced between 1973 and 1997.

In many SSA countries, capture fisheries have ill-defined use rights. The resource is usually owned by the state but managed as "regulated open access". Thus, fishers could harvest any quantity of fish if they comply with regulations set by central or local authorities. It has been argued that community-based resources are not generally overexploited as predicted by Hardin's "tragedy of the commons". However, if the group using the resource is relatively unstable, if the members of the group do not have adequate information about the condition of the resource and if information about the expected flow of benefits and costs is not available at a low cost to the resource users, there may be little incentive for the community to design rules to manage the resource (Ostrom, 2000).

Unfortunately, there is free mobility of fish stocks across communities and countries. Moreover, some of the fisheries are characterized by unpredictable seasonal growth rates due to upwellings. In some cases, state institutions have enacted conflicting policies at different points in time, which inevitably created mistrust between fisheries departments and fishers. Furthermore, inadequate policies of regulatory authorities provide opportunity for self-interested fishers to use illegal fishing technologies. For example, mesh size regulations in multi-species fisheries, with small and large pelagic species, are considered illegitimate by many fishers and are therefore heavily violated in many fishing communities. Moreover, capture fisheries regulations are generally poorly enforced as a result of limited budgets in state institutions responsible for enforcement, corrupt enforcement officers who solicit bribes from violators and an unenthusiastic judiciary that assigns minimum or no punishment to violators of fishing regulations. Commercial fishers, who use fishing vessels compete with local fishers for inshore fish stocks, degrade habitat and interrupt the fish food chain (Sterner, 2003). This has often led to conflicts and loss of property.

In 2001 aquaculture output in SSA was about 55,000 tonnes, about 0.15% of world food aquaculture output. Between 1970 and 2000 the annual average growth rates in aquaculture output was 8.8% compared to the global average of 9.2% (FAO, 2003b). Although the practice has been around since the 1850s and 1920s in South Africa and Kenya respectively, it is fairly new to many SSA countries.

The total production of food fish in SSA in 1997 was 3.7 million tonnes and may almost double by the year 2020. SSA is exporting an important part of its fish production into the world market (under various produce/product schemes: low-value food fish, high-value finfish, fish oil, etc.). This global picture shows high variation between individual countries in region. For example, Senegal, Mauritania, Namibia, South Africa, Nigeria, etc., are making huge catches of fish while countries like the D.R. Congo do not and are still relying on importation from Europe.

2.4.2 Aquatic ecosystems management and biodiversity potential

Aquatic ecosystems are stocks of resources whose sustainable extraction should alleviate poverty. Africa and Madagascar are divided in 11 bioregions and 93 freshwater ecoregions (Roberts, 1975; Hughes and Hughes, 1992; Stiassny, 1996; Shumway et al., 2002). An ecoregion is defined as a large area of land or water containing a distinct assemblage of natural communities and species, whose boundaries approximate the original extent of natural communities before major land use change (Dinerstein et al., 1995). These communities share most of their species, dynamics and environmental conditions and function together effectively as a conservation unit, usually following the boundaries of drainage basins and often serving as biogeographic barriers.

African ichthyofauna are rich in biodiversity and can be divided among 9 provinces (excluding the Great Lakes): Congolese (Zairian) province (690-700 species); Lower Guinean province (340 species); Upper Guinean province (over 200 species); Sudanian province (200-300 species); East Coast province (about 100 species); Zambezian (150 species); Quanza province (110 species); Southern (Cape) province (33 species); and Maghreb province (40 fish species) (Stiassny, 1996).

Most inland water fisheries are fished for basic needs by traditional and local communities, but fishing may not increase family income because of poor yields. Constraints include a lack of modern fishing vessels and insufficient knowledge of fish diversity, systematics and ecology (Shumway et al., 2002).

The Congo basin has very high endemism (about 80%), but fisheries management has failed in combining extractive uses of biodiversity with effective conservation policies. Riverine communities in the Congo basin use toxic plant extracts and some chemicals (such as pesticides) to catch fish from water systems. Fire is also used, especially during the dry season in the reproduction (frying) areas. These practices, of course, destroy fish diversity without the selection of individual sizes and species. Juveniles and fingerlings, which are the biological capital for the sustainable use of biodiversity, are the most vulnerable fish population groups. Increased poverty leads to high pressure on fish and in many cases the regeneration period is ignored. The decrease in fish size is sometimes due to this high pressure on the resource. "Use and conservation of renewable natural resources are widely (and wrongly) perceived as conflicting objectives. Foregone extractive use, for conservation, is viewed as a sacrifice, but the greater sacrifice (for future users) is to forego conservation. Conservation is itself a form of nonextractive use: insurance for continued production" (Pullin, 2004).

There exists a constant conflict between fish as food and fish as biodiversity, which requires wise management and sustainable conservation measures. The Congolese example illustrates four major challenges facing traditional fisheries:

1. The lack of appropriate fishing technologies that preserve fish capital (or the prevalence of illegal techniques and practices);
2. The lack of sustainable local fish markets (low overall incomes from fishing activities);
3. Poor produce conservation technologies (poor quality produce and decreasing market value); and
4. Overfishing of some water bodies (reduction of stock regeneration).

The combination of these elements is threatening aquatic biodiversity and the challenges facing capture fisheries and aquaculture in SSA are enormous. First, policy options that are available to address stock recovery may yield results in the long term, but small-scale fishers who are generally poor have immediate needs. Thus, fishers are usually reluctant to participate in implementing or accepting policies, such as seasonal closures (with short-term consequences), even though in the long-term food availability may increase.

Knowledge of fish stocks and the dynamics of aquatic ecosystems is important for designing sustainable fishery management policies. SSA countries lack the relevant data and as a result formulate ad hoc policies to address problems of complex fishery systems. A typical example is the use of a uniform mesh size regulation to curtail overexploitation of a multispecies fishery that is characterized by seasonal upwellings, which is also a transboundary resource.

The need to completely enforce fishing regulations that affect both small-scale fishers and industrial fleets is crucial. The limited budget of state institutions responsible for enforcing regulations coupled with widespread corruption among fishery officers and the fact that fishers consider some regulations illegitimate paints a gloomy picture for the industry. State institutions in Africa are generally weak and unable to cope with the activities of industrialized fleets (Fisheries Opportunities Assessment, 2006) (Box 2-1). Moreover the judicial systems in most countries are reluctant to enforce fishery regulations, which are generally considered of less importance.

There are a number of potential challenges that confront aquaculture in SSA. These include the provision of information, training and credit, the availability of fishmeal and fish oil for cultivation and mitigating the likely environment impact of semi-intensive aquaculture. Substituting vegetable protein for fishmeal may result in a higher mortality rate and low rate of growth of several aquatic species (Delgado et al., 2003). Intensive aquaculture requires the

Box 2-1. African fisheries management

"African fisheries management is characterized by institutions that have been too weak to cope with the burdens of controlling industrial fleets and empowering small-scale fishers. With few exceptions, they have been unable to stand up to European fishing fleets and other powerful fishing interests. They have largely failed to establish a coherent system of regulations that limit entry, reduce capacity, establish appropriate fisheries management reference points, enforce gear regulations and spatial and time restrictions, and redirect subsidies away from production." (Fisheries Opportunities Assessment, 2006) use of compound feeds, pesticides and antibiotics. The spillage of these substances into natural aquatic systems may negatively affect these ecosystems.

African fish biodiversity is not well-known; only very few species are well-known, particularly the Cichlid family (Tilapia and Nile perch being the star fish groups). Large fish such as *Distichodus sexfasciatus, Labeo sp, Mormyrops anguilloides, Bagrus sp., Synodontis sp., Schilbe mistus,* etc. and various catfish species are not well-known. The western, southern and eastern African sub-regions aquatic ecosystems and biodiversity are quite well studied, while the Congo Basin is poorly known and scientific work is needed.

Africa has a large potential for fish farming, with 37% of its surface area suitable for artisanal aquaculture and 43% suitable for commercial fish production (Aguilar-Manjarrez and Nath, 1998). Africa contributed about 4% to global aquaculture production and has been expanding production since 1984 at a rate equal to or greater than the global rate, albeit from a much smaller base (FAO, 1997). Traditional extensive African aquaculture systems are common throughout SSA region, especially in the West African sub-region (ICLARM-GTZ, 1991). Nigeria and Egypt provide 90% of output from African aquaculture, Madagascar and Zambia (together) contribute 4% and the rest of the continent provides 5-6% (FAO, 2000b).

Drain-in pond types (*ouedos* and *ahlos*) are mainly used to culture tilapias (Cichlids) in West and central Africa. In the D.R. Congo, especially the Imbongo region (Kikwit), drain-in ponds are traditionally used to culture tilapias, catfish (locally named *ngolo*) such as *Clarias angolensis*, *C. lazera*, *C. gariepinus*, etc., and a common edible aquatic herb (*Hydrocharis chevalieri*) primarily for local consumption. Where cultivated, each family in the village possesses its own pond for *Hydrocharis* cultivation (Brummett and Noble, 1995; Musibono and Mbale, 1995).

Over 90% of cultured fish in SSA come from earthen ponds of 200-500 m^2 fed with locally available, low-cost agricultural by-products and with limited yields (1000-2000 kg ha^{-1} yr^{-1}) (King, 1993). Periurban areas are promising zones for the development of aquaculture as an important source for nutrients and income generation and are playing an essential role in aquaculture, especially in Malawi, Cameroon, Nigeria, Ghana, Zambia and D.R. Congo.

In Zambia, the Kafue Fisheries Company, with 1870 ha, is the largest integrated fish farm in Africa. They produce indigenous tilapias (*Oreochromis andersonni, O. mossambicus, O. niloticus*), catfish (*Clarias gariepinus*) and carps (*Cyprinus carpio*). In the D.R. Congo, aquaculture was important during the colonial period (prior to the 1960s). Many aquacultural stations, such as Gandajika (Kasai), Nzilo (Katanga), Atwum/Imbongo (Bandundu), Kasangulu (Bas-Congo), were productive. After independence, the US Peace Corps tried to rehabilitate these ponds and to promote new aquaculture stations countrywide without success. Now aquaculture is getting more attention around large cities. In Kinshasa, for example, the Monastery "Notre-Dame de l'Assomption", Kimpoko/Nsele, Maluku, Kasangulu, Bateke, Mungulu-Diaka aquaculture stations are promising. Flooded areas along river courses (e.g., Congo, Kasai, Kwilu, Lamon rivers) are also periodically used for fish culture (Musibono, 1992).

Aquaculture in the SSA is still negligible compared to the potential offered by water resources and aquatic species (fish, crustaceans, snail, alligators, plants, etc.). AKST input into capture fishing and aquaculture is still very low, though increasing. Over 7,502 freshwater fish species are distributed in natural water bodies of 48 countries. Africa also boasts large natural and man-made lakes, which are important fish habitats and conservation areas (WRI, 1998).

Bio-invasion. Alien species are organisms that have been introduced intentionally or accidentally outside of their natural range. Alien invasive species are considered to be the most detrimental to pristine ecosystems and their dependent biodiversity (Williamson, 1996; McNeely, 2001). The Nile perch, *Lates niloticus*, intentionally introduced to Lake Victoria (Uganda) in the 1960s has tremendously reduced the indigenous tilapia population (WRI, 2002). In the Congo River, the invasive fish species *Heterotis niloticus*, accidentally introduced from Upper Ubangi River in the 1970s, is colonizing water bodies, especially rivers (Shumway et al., 2002).

Invasive species can be plants, algae, microorganisms, fish or other aquatic taxa. Water hyacinth, *Eichornia crassipes*, brought from South America by colonial administrations in the 1800s, is now widely spread in rivers and lakes, ponds, etc. In ponds, aquatic ferns, *Salvinia nymphllula*, *Salvinia molesta* and the Nile salad *Pistia stratiotes*, which are native, have become invasive and are reducing fish production. A native fish *Citharinus gibbosus* of the Congo River seasonally becomes invasive rendering fishing less productive. The water hyacinth case is a key example of the complexity of invasive species establishment and management (Rachmeler, 2003; Bartley and Martin, 2004; Howard, 2004).

Management of invasions. The best management strategy is based on prevention. Similar to other ecosystems, control of invasion in water-dependent ecosystems can be accomplished through:

1. Mechanical methods (removal, destruction, trapping or catching);
2. Chemical application (control by pesticides/herbicides and poisons);
3. Biological process (control of exotics being done by exotic biocontrol agents);
4. Ecosystem manipulation (such as the management of watersheds, water management, pollution control, competition with crops or local species); and
5. Integrated management (based on the association of some or all above strategies).

Biological pest control may be the best solution from the ecosystem health perspective, but the response may be slow. In SSA water bodies, for example, biological control of water hyacinth *Echhornia crassipes* using insects was not successful (Rachmeler, 2003).

The best invasive control, in many cases, is to give economic value to the invasions. When invasive fish species like *Heterotis niloticus* (also named *Kongo sika* or *Zaiko* in the D.R. Congo) is converted into capture and well marketed, fishing pressures on it will increase (reducing the negative impact on the ecosystem).

Nile tilapia (*Oreochromis niloticus*) has become invasive in many African water bodies (rivers, lakes, wetlands). The invasive nature of *Oreochromis niloticus* in Lake Victoria, East Africa and in the Congo Basin is well known. It competes with other cichlids such as *Oreochromis esculentus* and O. *variabilis* (Twongo, 1995). This fish species is now very valuable in Lake Victoria. In Kinshasa, the monk fish farm Prieuré Notre-Dame d'Assomption introduced *Oreochromis niloticus* in the 1980s; it is now widely spread and commonly sold (becoming therefore an important source of income and nutrients).This is also true with *Heterotis niloticus,* recently escaped from the upper Ubangi river (Central African Republic) and which has invaded the Congo river and tributaries. In the beginning fishers complained, but now are benefiting from this fish species and satisfying consumer needs in Kinshasa (Musibono, 1992; Shumway et al., 2002).

Mangroves, which are important spawning areas in coastal zones, are being degraded by various factors such as pollution from oil companies, deforestation for charcoal production and fishing with chemicals.

2.4.3. Quality of produce and productivity

As stated above, most production systems are artisanal and traditional. Aquaculture production systems are increasing and may become the main fish supply (ICLARM-GTZ, 1991; Jamu and Brummett, 2004).

Timing of extraction. Fishing (capture) occurs more during the dry season. During the rainy reason, fish species move into the spawning areas in marshes, grasses and other plant systems, and fishing is not allowed. Unfortunately, where traditional fishing is dominant, fishers are increasingly exploiting spawning areas with chemicals such as pesticides and toxic plant extracts. These practices are poverty-induced and anti-conservationist, especially in the D.R. Congo (Shumway et al., 2002). Indeed, the use of poisons in spawning zones destroys the biodiversity, especially eggs, fingerlings and juveniles and the renewal of the fish stock is thus compromised.

Processing, value-addition and utilization. The fish industry is very poor in the SSA region, except in South Africa, Uganda, Nigeria, Mauritania, Mauritius, Namibia and partly Ghana where fish are processed for export. In South Africa and Madagascar, fish are even canned. In most cases, fish are well processed for export. Local markets do not enforce minimum standards.

The potential for the fish industry is high, but as yet undeveloped. An increase in industry will result in an increase in the market value of fish. Promoting the fish processing industry in SSA will help maintain fish biodiversity and help reduce poverty.

Fisheries and aquaculture in SSA offer a huge potential for sustainable development. Unfortunately, fish biodiversity, systematics, ecology and conservation strategies are not well-known. Despite the fact that most SSA countries have signed the Convention on the Biological Diversity, AKST inputs remain negligible. Due to high biodiversity indices, the Congo Basin needs particular attention to fish biodiversity management. Ongoing work by a US NGO, Innovative Resources Management, the American Museum for Natural History and their local partner Environmental Resources Management and Global Security could be supported.

2.5 Bioenergy

Biomass is a renewable energy resource derived from the carbonaceous waste of various human and natural activities. It is derived from numerous sources, including the by-products from the timber industry, agricultural crops, raw material from the forest, household waste and wood. Biomass is the most important source of energy in Africa today, meeting more than 50% of its total primary energy consumption of 20.7 EJ (IEA, 2002). However, while much of the public discussion in the world today is focused on modern, efficient and potentially environmentally sustainable forms of bioenergy, Africa relies to a great extent on traditional sources of bioenergy that are associated with considerable social, environmental and economic costs.

African countries are the most intense users of biomass in the world and there is a strong correlation between the use of biomass as a primary energy source and poverty (Table 2-2). In the poorest countries the share of biomass in residential energy consumption can reach up to 90%. Similarly, within countries the use of biomass is heavily skewed towards the lowest income groups. In rural areas 92% of the population does not have access to electricity and thus has to rely almost entirely on biomass, LPG and kerosene to meet its energy needs (IEA, 2002).

Predominantly, this biomass energy consists of unrefined traditional fuels such as firewood and crop and animal residues used for essential survival needs such as cooking, heating, lighting, fish-smoking and crop drying. For example, in Kenya, Tanzania, Mozambique and Zambia, nearly all rural households use wood for cooking and over 90% of urban households use charcoal. These forms of traditional bioenergy are associated with considerable social, environmental and economic costs and are believed to be a consequence of poverty and at the same time an inhibitor to social and economic development (UNDP, 2000; IEA, 2002; Karekezi et al., 2004).

The energy efficiency of traditional biomass fuels is very low, especially when used in traditional cooking stoves, leading to a variety of problematic effects. First, the amount of fuel necessary to generate one unit of energy service (e.g., kilogram of wood per lumen of light) is very high, putting considerable strain on those environmental resources that supply the biomass. This poses a threat to natural vegetation but is also problematic for agricultural and animal residues, which are not available as fertilizer or fodder when they are used as energy sources. Inefficient combustion of biomass in traditional cooking stoves is also responsible for high levels of indoor air pollution leading to poor health. Each year 2.5 million premature deaths are caused by the fumes generated by traditional biomass stoves (WHO, 2002). Moreover, traditional sources of bioenergy are often associated with time-consuming and burdensome collection. In many cases, women and children are forced to devote several hours each day to the collection of fuel for cooking, significantly reducing the time they can devote to other productive activities, such as farming and education (UNDP, 2000; IEA, 2002; Karekezi et al., 2004; World Bank, 2004).

Modern energy services can alleviate many of these

Table 2-2. *Biomass energy use in sub-Saharan Africa (2003).*

Country	Combustible renewables and waste (% of total energy)	GDP per capita (constant 2000 US$)
South Africa	11	3,181
Namibia	15	1,943
Senegal	53	445
Gabon	59	3,867
Zimbabwe	60	479
Congo, Rep.	62	935
Angola	66	740
Cote d'Ivoire	66	573
Ghana	67	269
Benin	69	325
Togo	71	243
Kenya	78	418
Cameroon	79	723
Nigeria	79	387
Sudan	81	423
Zambia	81	327
Mozambique	86	262
Ethiopia	91	120
Tanzania	92	300
Congo, Dem. Rep.	94	85
Sub-Saharan Africa	57	528
Latin America & Caribbean	15	3,749
South Asia	39	498
High income: OECD	3	28,055

Source: World Bank, 2006.

problems by increasing energy conversion efficiency, reducing indoor air pollution and alleviating the strain on the surrounding environment. Consequently, access to modern energy services is generally viewed as a necessary, albeit in no way sufficient requirement for economic and social development and efforts are underway in many African countries to gradually transition to more efficient fuels (World Bank, 2004). It should be noted that this transition is not a linear process, but involves, depending on the local circumstances, several steps, including wood, charcoal, LPG, kerosene and eventually electricity. In most cases during this transition, several different sources of energy are used simultaneously for different end-uses within each household (IEA, 2002; Karekezi et al., 2004).

Modern bioenergy, i.e., the efficient production of modern energy services such as liquid biofuels, electricity and heat from biomass, offers one of several options to modernize the supply of energy services. Generally, the cost-competitiveness of bioenergy with respect to other sources of energy is highly dependent on local circumstances, e.g., the availability and price of alternative energy sources, the nature of energy distribution networks, the special distribution of energy consumers, availability of sufficient biomass feedstock, etc. While the generation of electricity through biomass digesters or cogeneration plants is often associated with net social benefits and there seems to be ample potential in Africa, the benefits of producing liquid biofuels for transportation are less clear and subject to fierce debate. The economics as well as certain environmental and social externalities are heatedly debated and no consensus has yet developed in the scientific community (see Global Report, Chapters 3, 4 and 6).

Several African countries have invested in modern sources of bioenergy, most prominently in cogeneration facilities to generate electricity and process heat and in the production of biofuels. In total, it is estimated that such modern bioenergy contributes about 4.7% of primary energy in Africa today (Kartha et al., 2005).

Malawi has been at the forefront of fuel ethanol development in Africa, being the only country outside of Brazil to have consistently blended ethanol into gasoline for more than 20 years (World Watch Institute, 2006). Similarly, Mauritius has been able to successfully produce electricity through cogeneration plants, predominantly from sugar cane bagasse. Several other African countries, e.g., Ghana, Ethiopia, Kenya, South Africa, Mali, Nigeria, Zambia and Benin currently have, or are planning to introduce, active biofuels policies (Dufey, 2006; IEA, 2006; World Watch Institute, 2006).

2.6 Sociocultural Issues

The peoples of sub-Saharan Africa belong to several thousand different ethnic groups. Each ethnic group has its own language, tradition, history, way of life and religion. These cultural differences and resource endowments affect agricultural practices in the region. In particular they are reflected in land use strategies. Different strategies requiring different types of expertise will be needed, in the transfer of technology to pastoral herders, for example, in contrast to permanent field agriculturalists.

Women and men are assigned both distinct and complimentary roles in agriculture. Time allocation studies have been done which aimed at determining which household members are tasked with specific farm tasks (Saito et al., 1992).

A typical farm household in SSA is based on the clear distinction between men's and women's roles, including management of different types of production either individually or together; individual responsibility for mobilizing the factors of production through barter or monetary exchanges for individual or joint use; defined patterns for the exchange of goods and services among the household members; and elaborate arrangements that determine who makes decisions with regard to selling, consuming, processing and storing agricultural products (Box 2-2). In Kenya women reported that men were responsible for building the granary while women were responsible for hand digging, harvesting and transporting crops. Though tasks may be viewed as the

Box 2-2. Farm household roles in sub-Saharan Africa

Household, farming or enterprise activity:

Men: cash crops, large livestock

Women: child rearing and household maintenance (including food preparation, gathering water and fuel), food and horticultural crops, small livestock, agroprocessing and trading (home based)

Farming tasks:

Men: clear land

Women: plant, weed, process and store agricultural products

Separate fields and plots:

Men and women each responsible for own inputs and controlled outputs

Jointly managed plots:

Men and women share labor input, use proceeds for family purposes

Land rights:

Men: ownership

Women: insecure land tenure; determined by husband or male relatives

Input rights:

Men: right to resources such as land, labor, technical information and credit

Women: access to these resources determined by men

Source: Pala, 1983; author elaboration.

responsibility of men or women, in practice the divisions are blurred, with both men and women involved in many tasks (Pala, 1983).

The situation of a crop such as maize has its peculiar dynamics in the division of labor. Maize is grown both as a cash and subsistence crop, with high yielding varieties marketed as cash crops. As a result the local varieties were labeled as women's crops and the high yielding ones were labeled as men's. As high yielding varieties that meet the consumption preferences of small holder farmers are developed, the distinction between subsistence and cash crops becomes blurred. Evidence from Malawi suggested that both hybrid maize and local maize can be viewed as either subsistence or cash crop depending on the farmers circumstances (Smale and Heisey, 1994).

The traditional cultural, social and economic norms governing farm households in sub-Saharan Africa began to change dramatically in the 1970s. The rapid increase in population pressure overwhelmed traditional farming systems. The perceived employment opportunities in urban areas, mines, plantations led to high rate of rural to urban migration especially among men. As men seek other opportunities for increased income they are likely to migrate, leaving women to take over the traditionally male tasks. In addition, when men engage more in non-farm activities, women become more involved in cash cropping. The gender division of labor is changing and it does not appear that men are assuming women's agricultural activities particularly in the production of food for home consumption (Doss, 1999).

When men move into activities that are traditionally women's, they are not substituting their labor for their wives labor within the household (Zuidberg, 1994). The case often is that women's activities have become more productive or profitable. An example is drawn from Burkina Faso, where women traditionally picked shea nuts. When the sale of these became profitable, men became involved in this activity often with the assistance of their wives. The number of female-headed households is increasing in sub-Saharan Africa.

The willingness to adopt new technology is dependent firstly on farmer expectations for increased output or the mitigation of such constraints from its use. One such constraint is the lack of or limited access to labor. A number of factors account for the households' labor constraints. These include the gender division of labor, access to household labor and access to hired labor. Different crop technologies may require concentrations of labor at different times of the season. To the extent that women and men perform different tasks or have different access to outside resources, the gender of the farmer may affect the adoption of technology.

The adoption of technology has resulted in a shift in the gender division of labor. A study done in Tanzania reported that men became more involved in agriculture as the use of the plough became more widespread as hybrid maize gained popularity (Holmboe-Ottessen and Wandel, 1991). In Zambia, households that adopt new technologies present a situation in which men work more on crops and animals and less on non-farm tasks while women spend less time on crops and more on post-harvest activities. Children shift from tending crops to tending animals.

In SSA new technologies have been introduced to increase agriculture production. These technologies are based on the use of agriculture inputs such as fertilizer, seeds and the associated extension services. Women have less access to these inputs than men. Fertilizer use is dependent on its availability in the area at the appropriate time and the farmer's ability to purchase fertilizer (Doss, 1999). The impact of fertilizer use on productivity also depends on whether farmers apply it appropriately on their fields. Zambia presents a typical case of frequent non-availability of fertilizer in farming areas. Over the years farmers have complained about the non-availability or late delivery of inputs such as fertilizer and seed. Associated with this is the prohibitive price of fertilizer. Most farmers are not able to afford the required amount of fertilizer for maximum production.

The situation is worse for women who have difficulties accessing fertilizer and in instances when it is available, can ill afford to purchase it due to their limited financial resources. Fertilizer subsidies increase maize production among women farmers and increase household food security. In Cameroon and Malawi the removal of subsidies has affected female more than male farmers because they reduce the use of fertilizer on local maize, which is a woman's crop (Gladwin, 1991).

The failure to incorporate women's roles in implementing technological change has three interrelated consequences. First, there is loss of adaptive efficiency from not taking their operational knowledge into consideration; second, there is a reduction in women's household bargaining position accompanied by an increase in their work. Third, there are lower adoption rates due to their lack of access to technology and training and failure by the proponents of the technology to address women's time constraints (Muntemba and Blackden, 2000).

Use of timely and appropriate extension services can result in higher yields (Saito and Weidman, 1990). Due to the social and cultural positioning of women it is evident that in most cases women do not get the benefits of extension services. Several factors account for this: 1) poor timing for extension services provision; 2) taboos surrounding male extension staff and female farmers interactions; 3) low literacy levels among women compared to men; 4) immobility on the part of women thus limiting their access to extension services; and 5) language differences.

Some efforts to reach women through extension services have proved a success in Zimbabwe where a group approach was used in crop production, thereby attracting extension services (Muchena, 1994). Africa's vast potential is not tapped; many countries have great potential to produce food and traditional agriculture exports for themselves, their neighbors, the region and the international market. Consistent and transparent institutions are essential to success.

Africa's witnessed institutional expansion and reform post-independence between 1960 and 1985. Newly independent governments invested in education. For example, at independence Botswana had only 40 graduates. In 1960, 90% of agriculture researchers in Africa were expatriates. Governments began to Africanize the civil service, increase school enrolments, and build universities. The first university in Zambia was built through material and financial donations from the public. Thousands of students in SSA were sent abroad for undergraduate degrees and graduate level training. Donors supported this human capital development through financing the construction of universities and creating faculties of agriculture. The number of extension workers in SSA increased from 21,000 in 1959 to 57,000 in 1980; universities increased from around 20 in 1960 to 160 in 1996 (Eicher, 1999). The number of full-time equivalent agriculture scientists increased from around 2000 in 1960 to 9000 in 1991.

During 1985 to 1999 public universities were downsized as were research institutions and extension services as parastatals were privatized and foreign private investments were expanded (Eicher, 1999). This resulted from Structural Adjustment Programs (SAP) instigated by the International Monetary Fund. These SAPs imposed conditionalities, which included downsizing the civil service.

New private institutions (seed and fertilizer companies and universities) are now in stiff competition with public counterparts. In most countries universities are the weak links in agriculture they are still relatively young and because they have experienced drastic cuts in their budgets. Privatizing the agriculture sector has had adverse effects on agriculture production. The capacity of the private sector to boost agriculture production has been under scrutiny and indications are that governments still need to play a significant role to allow for public private partnerships.

References

AATF. 2005. Harnessing the potential of public/private partnerships: The African agricultural technology foundation annual report. AATF, Nairobi.

Abassa, K.P. 1995. Improving food security in Africa: The ignored contribution of livestock. ECA/FAO, Addis Ababa.

Abate, T., A. van Huis, and J.K.O. Ampofo. 2000. Pest management strategies in traditional agriculture: An African perspective. Ann. Rev. Entomol. 45:631-659.

Aguilar-Manjarrez, J., and S.S. Nath. 1998. A strategic reassessment of fish farming potential in Africa: Cifa technical Pap. 32. FAO, Rome.

Ajayi, F.A., and N.E. Lale. 2001. Seed coat texture, host species and time of application affect the efficiency of essential oils applied for control of *Callosobruchus maculatus* in stored pulses. Int. J. Pest Manage. 47:161-166.

Alders, R.G., and P.B. Spradbrow. 1999. Newcastle disease in village chickens: A field manual. Maputo, Mozambique.

Allem, A.C., and S.K. Hahn. 1988. Cassava germplasm strategy for Africa. Crop genetic resources of Africa. Proc. Int. Conf. Nairobi. 26-30 Sep 1988. IBPGR, IITA, CNR, UNEP, Nairobi.

Allen, D.J., and J.B. Smithson. 1988. The regional program on bean, in southern Africa: Strategy and progress in plant improvement. Crop genetic resources of Africa. Proc. Int. Conf. Nairobi. 26-30 Sep 1988. IBPGR, IITA, CNR, UNEP, Nairobi.

AQUASTAT. 2005. Irrigation in Africa in figures: AQUASTAT survey 2005 [Online]. Available at http://www.fao.org/ag/AGL/AGLW/aquastat/regions/africa/index.stm. FAO, Rome.

ASARECA. 2006a. ASARECA's role in reducing poverty and hunger in Sub-Saharan Africa [Online]. Available at http://www.w1.co.ug/asareca/htdocs/ecapapa/archives.php. ECAPAPA Enewsl. 9(2).

ASARECA. 2006b. Agricultural production and soil nutrient mining in Africa: Implications for resource conservation and policy development [Online]. Available at http://www.w1.co.ug/asareca/htdocs/ecapapa/archives.php. ECAPAPA Enewsl. 9(9).

ASARECA. 2006c. Biotechnology stakeholder findings on GMOs and food policy choices for Sub Saharan Africa [Online]. Available at http://www.w1.co.ug/asareca/htdocs/ecapapa/archives.php. ECAPAPA E. Newsl. 9(11).

Asibey, E.O.A., and G.S. Child. 1990. Wildlife management for rural development in sub-Saharan Africa. Unasylva 41:3-10.

Asiedu, J.J. 1989. Processing tropical crops: A technological approach. Macmillan Education, London.

Asiedu, R., S.Y.C. Ng, D. Vuylsteke, R. Terauchi, and S.K. Hahn. 1992. Analysis of the need for biotechnology research on cassava, yam, and plantain. G. Thottapilly et al. (ed) Biotechnology: Enhancing research on tropical crops in Africa. Ebenezer Baylis, UK.

Ayele, W.Y., S.D. Neill, J. Zinsstag, M.G. Weiss, and I. Pavlik. 2004. Bovine tuberculosis: An old disease but a new threat to Africa. Int. J. Tuberc. Lung Dis. 8:924-937.

Bailey, S.W. 1954. Air-tight storage of grains: Its effects on insect pests 1: *Calandra granaria L.* Aust. J. Agric. Res. 6:33-40.

Barnes, R.D., D.L. Filer, and S.J. Milton. 1996.

Acacia karroo: Monograph and annotated bibliography: Trop. For. Pap. 32. Oxford Forestry Inst., UK.
Bartley, D.M., and F. Martin. 2004. Introduction of alien species/strains and their impact on biodiversity. M.V. Gupta et al. (ed) Use of genetically improved and alien species for aquaculture and conservation of aquatic biodiversity in Africa. The WorldFish Center, Penang.
Bassett, T.J. 2005. Card-carrying hunters, rural poverty, and wildlife decline in northern Cote d' Ivoire. Geograph. J. 171:24-35.
Bassett, T.J., and J. Crummey (ed) 2003. African savannas: Global narratives and local knowledge of environmental change. James Currey, Oxford.
Bationo, A., F. Lompo, and S. Koala. 1998. Research on nutrient flows and balances in West Africa: State-of-the-art. Agric. Ecosyst. Environ. 71:19-35.
Behnke, R., I. Scoones, and C. Kerven (ed) 1993. Range ecology at disequilibrum: New models of natural variability and pastoral adaptation in African savannas. ODI, London.
Bender, A. 1992. Meat and meat products in human nutrition in developing countries: Food Nutr. Pap. 53.FAO, Rome.
Bengis, R.G., R.A. Kock, and J. Fischer. 2002. Infectious animal diseases: The wildlife/ livestock interface. OIE Sci. Tech. Rev. 21:53-65.
Berthaud, J., and A. Charrier.1988. Genetic resources of Coffee. R.J. Clarke and R. Macrae (ed) Coffee agronomy. Elsevier, London.
Birgegard, L.E. 1993. Natural resources tenure: A review of issues and experiences with emphasis on sub-Saharan Africa. Swedish Univ. Agric. Sci., Uppsala.
Bizimana, N. 1994. Traditional veterinary practice in Africa. Ashburn, Germany.
Blench, R.M.B. 2001. Till the cows come home: Why conserve livestock diversity? I. Koziell and J. Saunders (ed) Living off biodiversity: Exploring livelihoods and biodiversity issues in natural resource management. IIED, London.
Blom, A., R. Van Zalinge, E. Mbea, I.M.A. Heitkonig, and H.H.T. Prins. 2004. Human impact on wildlife populations within a protected Central African forest. Afr. J. Ecol. 42:23-31.
Bohannan, P. 1963. Land, tenure and land tenure. *In* D. Biebuyck (ed) African agrarian systems. Int. African Inst., London.
Bokosi, J.M. 1988. Bean evaluation in Africa. p. 97-203. Crop genetic resources of Africa. Proc. Int. Conf., Nairobi, 26-30 Sep 1988. IBPGR, UNEP, IITA, CNR, Nairobi.
Bonkoungou, E.G. 1996. Drought, desertification, and water management in sub-Saharan Africa. Available at http://www.unu.edu/unupress/ unupbooks/80918e/80918E0l.htm. UN Univ., Tokyo.
Brady, N. 1990. The nature and properties of soils. 10th ed. MacMillan, New York.
Breman, H. 1995. Sustainable agriculture in the Sahel? Integrated perennials and fertilizers. p. 213-235. J. Bouma et al. (ed) Ecoregional approaches for sustainable land use and food production: Systems approaches for sustainable agricultural development. Kluwer Academic Publ., New York.
Briske, D.D., S.D. Fuhlendorf, and F.E. Smein. 2003. Vegetation dynamics on rangelands: A critique of current paradigms. J. Appl. Ecol. 40:601-610.
Bruinsma, J. (ed) 2003. World agriculture: Towards 2015/2030—An FAO perspective. FAO, Rome.
Brumby, P., and G. Gryseels. 1985. Stimulating milk production in milk deficit countries of Asia and Africa. p. 62-72. A.J. Smith (ed) Milk production in developing countries. Cent. Trop. Vet. Med., Univ. Edinburgh, UK.
Brummett, R.E., and R.P. Noble. 1995. Aquaculture for African smallholders. Tech. Rep. 46. ICLARM, Manila.
Buresh, R.J., P.A. Sanchez, and F. Calhoun (ed) 1997. Replenishing soil fertility in Africa. Soil Sci. Soc. Am. Spec. Publ. 51. Madison WI.
Carney, J.A. 1988. Struggles over land and crops in an irrigated rice scheme: The Gambia. p. 59-78. *In* J. Davison (ed) Agriculture, women and land: The African experience. Westview Press, Boulder.
Caswell, G.H. 1984. The value of the pod in protecting cowpea seed from attack by bruchid beetles. Samaru J. Agric. Res. 2:49-55.
Chandler, R.F.Jr. 1979. Rice in the tropics: A guide to the development of national programme. Westview Press, Boulder.
Cleaver, K.M., and G.A. Schreiber. 1994. Reversing the spiral: The population, agriculture and environment nexus in sub-Saharan Africa. World Bank, Washington DC.
Colson, E. 1971. The impact of the colonial period on the definition of land rights. p. 193-215. *In* V. Turner (ed) Colonialism in Africa, 1870-1960. Vol. 3. CUP, Cambridge.
Coppock D.L. (ed) 1994. The Borana plateau of southern Ethiopia: Synthesis of pastoral research, development and change: 1980-91. ILCA, Ethiopia.
Daborn, C.J., J.M. Grange, and R.R. Kazwala. 1996. The bovine tuberculosis cycle: An African perspective. J. Appl. Bacteriol. 81:527-532.
Das, S.M., and S.H. Mbaga. 2002. Importance of centralized recording scheme for dairy cattle to the development of livestock in Tanzania. Proc. Sci. Conf. Tanzania Soc. Anim. Prod. (TSAP), 20th, Arusha, 3-5 Dec 2002.
Das, S.M., and J.I. Mkonyi. 2003. Important aspects of conservation of indigenous cattle in Tanzania. Proc. Sci. Conf. Tanzania Soc. Ani. Prod. (TSAP), 20th, Tanga, 28-30 Oct 2003.
Das, S.M., J.K. Msechu, M.L. Kyomo, D.B. Mpiri, and S.W. Chenyambuga. 2003. State of farm animal genetic resources in Tanzania. TVA 20th Sci. Conf., Arusha, 2-4 Dec 2003.
David, S. 1998. Producing bean seeds: Handbook for small-scale bean producers. CIAT, Kampala.
De Castro, J.J., and R.M. Newson. 1993. Host resistance in cattle tick control. Parasitol. Today 9:13-17.
De Haan, C., H. Steinfeld, and H. Blackburn. 1997. Livestock and the environment: Finding a balance. WRENmedia, UK.
De Leeuw, P.N., L. Reynolds, and B. Rey. 1995. Nutrient transfer from livestock in West African agricultural systems. p. 371-392. J.M. Powell et al. (ed) Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa Vol. II. ILCA, Ethiopia.
Delgado, C.L., M. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 1999. Livestock to 2020: The next food revolution. FAE Disc. Pap. 28. IFPRI, Washington DC.
Delgado, C.L., N. Wada, M. Rosegrant, S. Meijer, and M. Ahmed. 2003. Fish to 2020: Supply and demand in changing global markets. IFPRI, Washington DC.
Demissie, A. 1991. Crop genetic resources of Africa: Potentially valuable crop plants in a vavilovian center of diversity: Ethiopia. p. 89-98. Proc. Int. Conf., Nairobi, 26-30 Sep 1988. IBPGR, UNEP, IITA, CNR, Nairobi.
Dery, B.B., R. Otsyina, and C. Nga'tigwa. 1999. Indigenous knowledge of medicinal trees and setting priorities for their domestication in Shinyanga Region, Tanzania. ICRAF, Nairobi.
Devendra., C., J. Morton, B. Rischkowsky, and D. Thomas. 2005. Livestock systems. E. Owens et al. (ed) Livestock and wealth creation: Improving the husbandry of animals kept by resources—poor people in developing countries. Nottingham Univ. Press, UK.
DeVries, J., and G. Toenniessen. 2001. Securing the harvest: Biotechnology, breeding and seed systems for African crops. CAB Int., U.K.
Dey, J. 1981. Gambian women: Unequal partners in rice development project? p. 109-122. N. Nelson (ed) African women in the development process. Frank Cass, London.
Dhlamini, Z. 2006. The role of non-GM biotechnology in developing world agriculture [Online]. Available at http:// www.scidev.net/dossiers/index .cfm?fuseaction=policybrief&dossier=6 &policy=114. Science and Development Network (SciDevNet).
Dike, M.C. 1994. An annotated checklist and the identity of major storage insect pests in Nigeria. Samaru Misc. Pap. 130:1-17.
Dike, M.C. 2005. Challenges of pests and

diseases to national efforts in sustained agricultural productivity. *In* V.B. Ogunlela et al. (ed) Proc. Nat. Conf. on prospects and prob. of agricultural development in N. states of Nigeria. Inst. for Dev. Res., Ahmadu Bello Univ., Zaria, Nigeria.

Dike, M.C., and G.B. Mshelia. 1997. Laboratory assessment of the efficacy of eucalyptus leaf and stem powders n the control of *Callosobruclus maculatus* (F.) on stored cowpea. Samaru J. Agric. Res. 14:11-18.

Dinerstein, E., D.M. Olson, D.J. Graham, A.L. Webster, S.A. Primm, M.P. Bookbinder et al. 1995. A conservation assessment of the terrestrial ecoregions of Latin America and the Caribbean. World Bank, Washington DC.

Dixon, J., A. Gulliver, and D. Gibbon. 2001. Farming systems and poverty. M. Hall (ed) Improving farmers' livelihoods in a changing world. Available at http://www.fao.org/DOCREP/004/ac349e/ac349e02.htm. FAO, Rome.

Doss, C.R. 1999. Twenty five years of research on women farmers in Africa: Lessons and implications for agricultural research institutions. Econ. Prog. Pap. 99-02. CIMMYT, Mexico.

Downs, R.E., and S.P. Reyna. 1988. Land and society in contemporary Africa. Univ. New Hampshire.

Drucker, A.G. 2001.The economic valuation of AnGR: Importance, application and practice. Proc. Int. Wrkshp Comm-Bsd. Manage. Animal Genetic Research, Mbabane, Swaziland. 7–11 May 2001. FAO, UNDP, Rome.

Dube, O.P., and G. Pickup. 2001. Effects of rainfall variability and communal and semi-commercial grazing on land cover in southern African rangelands. Clim. Res. 17:195-208.

Dufey, A. 2006. Biofuels production, trade and sustainable development: Emerging issues. IIED, London.

EC (European Commission). 1999. Final report of a mission carried out in Uganda from 19/8 to 20/8/1999 for the purpose of assessing controls on pesticide residues in fish coming from Lake Victoria. DG SANCO/1129/1999. EC, Brussels.

Eicher, C.K. 1999. Institutions and the African farmer. Third Distinguished Economist LectureCIMMYT, Mexico.

Eicher, C.K., K. Maredia, and I. Sithole-Niang. 2005. Genetically modified crops: A response to the African food crisis. ECAPAPA ENewsl. 8:13.

Ellis, J.E., and D.M. Swift. 1988. Stability of African pastoral ecosystems: Alternate paradigms and implications for development. J. Range Manage. 41:450-459.

Ervin, T.L. 1988. The tropical forest canopy: The heart of biotic diversity. p. 123-129. E.O. Wilson (ed) Biodiversity. Nat. Acad. Press, Washington DC.

Eswaran, H., R. Lal, and P.F. Reich. 2001. Land degradation: An overview. p. 20-35. *In* E.M. Bridges et al. (ed) 2001. Response to land degradation. Enfield Sci. Publ., New Hampshire.

FAD. 2003. Projet d'appui à la lutte préventive contre le criquet pèlerin dans quatre membres de la CLCPRO. (In French) Fonds Africain de Développement, Abidjan.

FAO. 1990. The major significance of «minor» forest products: Local people's uses and values of forests in the West African humid forest zone. Community Forestry Notes. FAO, Rome.

FAO. 1997. Review of the state of world aquaculture: Fisheries Circular 886, Rev. 1. FAO, Rome.

FAO. 1998. Integrated tick and tick-borne disease control programme: Project findings and recommendations. Available at http://www.fao.org/docrep/field/381303.htm. FAO, Rome.

FAO. 2000a. La Situation mondiale des pêches et de l'aquaculture (In French). FAO, Rome.

FAO. 2000b. Africa regional aquaculture review. Proc. of workshop, Accra, 22-24 Sept. CIFA Occas. Pap. 24. FAO, Rome.

FAO. 2000c. The state of the food insecurity in the world 2000. FAO, Rome.

FAO. 2001. State of the world's forests. FAO, Rome.

FAO. 2002. Agriculture: Towards 2015/2030. FAO, Rome.

FAO. 2003a. The state of food security in the world. FAO, Rome.

FAO. 2003b. State of the world's forests. FAO, Rome.

FAO. 2004a. Current world fertilizer trends and outlook to 2008/9. FAO, Rome.

FAO. 2004b. Public participation in decision-making regarding GMOs in developing countries: How to effectively involve rural people? Available at http://www.fao.org/biotech/logs/c12logs.htm. FAO, Rome.

FAO. 2004c. Statistical yearbook 2004. FAO, Rome.

FAO. 2005a. Irrigation in Africa, Europe and Latin America. Update of the digital global map of irrigation area: Version 4 [Online]. Available at http://www.fao.org/nr/water/aquastat/irrigationmap/index50.stm. FAO, Rome.

FAO. 2005b. Situation des forêts du monde (In French). FAO, Rome.

FAO. 2007. State of the world's forests. FAO, Rome.

FAOSTAT. 2005. Statistical database [Online]. Available at http://faostat.fao.org. FAO, Rome.

Fisheries Opportunities Assessment. 2006. Coastal Resources Center, Univ. Rhode Island and Florida Int. Univ.

Fletcher, S.M., P. Zhang, and D.H. Carley. 1992. Groundnut production, utilization and trade in the 1980s. p. 17-32. *In* S. Nigeria (ed) Groundnut: A global perspective. Proc. Int. Workshop, Pantancheru, India, 22-29 Nov 1991. ICRISAT, India.

Fuhlendorf, S.D., D.D. Briske, and F.E. Smeins. 2001. Herbaceous vegetation change in variable rangeland environments: The relative contribution of grazing and climatic variability. Appl. Veg. Sci. 4:177-188.

Gladwin, C.H. 1991. Fertilizer subsidy removal programs and their potential impacts on women farmers in Malawi and Cameroon. p. 191-216. *In* C.H. Gladwin (ed) Structural adjustment and African women farmers. Univ. Florida Press, Gainesville.

Goldman, L., and N. Tran. 2002. Toxics and poverty: The impact of toxic substances on the poor in developing countries. World Bank, Washington DC.

Goli, A.E., F. Begemann, and N.Q. Ng. 1991. Germplasm diversity in bambara groundnut and prospects for crop improvement. Crop genetic resources of Africa. Proc. Int. Conf. Nairobi, 26-30 Sept 1988. IBPGR, UNEP, IITA, CNR, Nairobi.

Gotoh, K., and T.T. Chang. 1979. Crop adaptation. p. 234-257 J. Sneep and A.J.T. Hendricksen (ed) Plant breeding perspectives. Centennial publication. Konionklijk Kweekbedrijf en Zaadhandel D. J. van der Have. Centre Agric. Publ. Doc., Wageningen.

Greathead, D.J. 1967. A review of biological control in the Ethiopian Region. Tech. comm. 5. Commonwealth Inst. Biol. Control, UK.

Grist, D.H. 1953. Rice. Longman, Green and Co., London.

Gryseels, G. 1988. The role of livestock in the generation of smallholder farm income in two vertisols areas of the central Ethiopian highland. S.C. Jutzi et al. (ed) Management of vertisols in sub-Saharan Africa. ILCA, Addis Ababa.

Hardin, G. 1968. The tragedy of the commons. Science162:1243-1248.

Harkness, C. 1970. The trade in Nigerian groundnuts. Samaru Agric. Newsl. 12:62-65.

Heap, R.B. 1994. Can the new biotechnology increase agricultural production in sub-Saharan Africa? p. 32-45. V. Ravichandran and R.R. Daniel (ed) The role of science in food production in Africa. COSTED-IBN, Madras, India.

Hein, L. 2006. The impacts of grazing and rainfall variability on dynamics of a Sahelian rangeland. J. Arid. Environ. 68:488-504.

Heinemann, J.A. 2007. A typology of the effects of (trans)gene flow on the conservation and sustainable use of genetic resources. FAO, Rome.

Henning, M.W. 1956. Animal diseases in South

Africa. 3rd ed. Central News Agency, Johannesburg.
Holmboe-Ottesen, G., and M. Wandel. 1991. Wife, today I only had money for pombe: Gender and food: Women's bargaining power and agricultural change in a Tanzanian Community. K.A. Stolen and M. Vaa (ed) Gender and change in developing countries. Norwegian Univ. Press, Oslo.
Howard, G.W. 2004. Invasive species in water-dependent ecosystems. p. 22-26. M.V. Gupta (ed) Use of genetically improved and alien species for aquaculture and conservation of aquatic biodiversity in Africa. The WorldFish Center, Penang.
Hughes, R.H., and J.S. Hughes. 1992. Directory of African wetlands. IUCN, Switzerland.
Humavindu, M.N., and J.I. Barnes. 2003. Trophy hunting in the Namibian economy: An assessment. S. Afr. J. Wildl. Res. 33:2:65-70.
Hursey, B.S., and J. Slingenbergh. 1995. The tsetse fly and its effect on agriculture in sub-Saharan Africa: World animal review, 50 Years. FAO, Rome.
Hussey, N.W. 1990. Agricultural production in the third world: A challenge for natural pest control. Exp. Agric. 26:171-183.
ICLARM-GTZ. 1991. The context of small-scale integrated agriculture-aquaculture systems in Africa: A case study of Malawi. ICLARM Stud. Rev. 18. The WorldFish Center, Penang.
IEA. 2002. World energy outlook 2002. IEA. Paris.
IEA. 2006. World energy outlook 2006. IEA. Paris.
IITA. 2004. Research highlights: Annual report 2004. IITA, Ibadan.
ILRI. 2001. ILRI strategy to 2010: Making the livestock revolution work for the poor. ILRI, Nairobi.
ILRI. 2003.The livestock revolution. ILRI, Nairobi.
IRRI. 1993. Rice almanac. IRRI, Manilla.
Jacobsen, P. 1991. ECF immunisation in southern highlands, 1990-1991. Proc. Sci. Conf. Tanzania Vet. Assoc. (TVA) 9th, Arusha, 3-5 Dec 1991.
Jahnke, H.E. 1982.Livestock production systems and livestock development in tropical Africa. Keiler Wissenschaftsverlag Vauk, Germany.
Jamu, D., and R.E. Brummett. 2004. Opportunities and challenges for African aquaculture. The WorldFish Center, Penang.
Kabayo, J.P. 2002. Aiming to eliminate tsetse from Africa. Trends Parasitol. 18:473-475.
Kabeh, J.D., and N.E.S. Lale. 2004. Effect of preharvest sprays of neem (*Azadirachta indica* A. Juss) seed products and pirimiphos methyl and harvest seed modification on infestation of cowpeas by storage bruchids in the field and store in Maiduguri, Nigeria. Nigerian J. Entomol. 21:104-116.
Kajoba G.M. 1993. Food crisis in Zambia. Zambia Printing Co., Lusaka.
Kambewa, B.M.D., M.-W. Mfilitilodze, K. Huttner, C.B.A. Wollny, and R.K.D. Phoya. 1997. The use of indigenous veterinary remedies in Malawi: Ethnoveterinary medicine, alternatives in livestock development. Proc. Int. Conf., Pune, India. 4-6 Nov 1997. BAIF Dev. Res. Found., Pune.
Kamuni, P.M., J.S. Oketch, and C. Huggins. 2005. Land access and the return and resettlement of IDPs and refugees in Burundi. p. 195-267. *In* C. Huggins and J. Clover (ed) From the ground: Land rights, conflict and peace in sub-Saharan Africa. African Centre for Technology Studies, Nairobi and Inst. for Security Studies, Pretoria.
Karekezi, S., K. Lata, and S.T. Coelho. 2004. Traditional biomass energy: Improving its use and moving to modern energy use. Thematic background paper. Int. Conf. Renewables, Bonn, 1-4 June 2004. GTZ.
Kartha, S., G. Leach, and S.C. Rajan. 2005. Advancing bioenergy for sustainable development: Guidelines for policymakers and investors. ESMAP, Washington DC.
Kelly, V. 2006. Factors affecting demand for fertilizer in sub-Saharan Africa. ARD Disc. Pap. 23. World Bank, Washington DC.
King, H. 1993. Aquaculture development and environmental issues in Africa. R. Pullin et al. (ed)
Environment and aquaculture in developing countries. ICLARM, Manila.
Kirk, E. 1996. The role of land tenure and property rights in sustainable resource use: The case of Benin. *In* Guiding principles: Land tenure in development cooperation. GTZ, Eschborn.
Kirkby, R.A. 1990. The ecology of traditional agroecosystems in Africa. p. 173-180. *In* M.A. Altieri and S.B. Hecht (ed) Agroecology and small farm development. CRC Press, Boca Raton.
Kochlar, S.L. 1986. Tropical crops: A textbook of economic botany. Macmillan, New York.
Kuiseu, J., and A. Thiam. 2006. Locust in the Sahel: Delayed response is fatal. Agric. Rural Dev. 13:63-64.
LEAD (Livestock, Environment and Development). 2003. Livestock and environment toolbox.Available at http://lead.virtualcentre.org/en/dec/toolbox. FAO, Rome.
Leakey, R.R.B., and Z. Tchoundjeu. 2001. Diversification of tree crops: Domestication of companion crops for poverty reduction and environmental services. Exp. Agric. 37:279-296.
Leakey, R.R.B., Z. Tchoundjeu, K. Schreckenberg, S.E. Shackleton, and C.M. Shackleton. 2005. Agroforestry tree products (AFTPs): Targeting poverty reduction and enhanced livelihoods. Int. J. Agric. Sustainability 3:1-23.
Lebbie, S.H.B. 1996. Livestock and food security in smallholder production systems in Africa: Beyond meat and milk. p. 381-396. *In* Food security in Africa: Challenges, opportunities, and targets for animal production. Proc. Conf. South African Society of Animal Science, Germiston, South Africa.
Leisz, S. 1998. Burundi Country Profile. J. Bruce (ed) Country profiles of land tenure: Africa. Research Pap. 130. Land Tenure Center, Univ. Wisconsin, Madison.
MA (Millennium Ecosystem Assessment). 2005. Ecosystems and human well-being: Current state and trends: Findings of the conditions and trends working group. Island Press, Washington DC.
Maghembe, J.A., A.J. Simons, F. Kwesiga, and M. Rarieya. 1998. Selecting indigenous trees for domestication in Southern Africa: Priority setting with farmers in Malawi, Tanzania, Zambia and Zimbabwe. ICRAF, Nairobi.
Makkar, H.P.S., and G.J. Viljoen (ed) 2005. Application of gene-based technologies for improving animal production and health in developing countries. Springer, Netherlands.
Marley, P.S. 1996. The importance of fungi in cereals grain storage. NOMA 12:13-17.
Marples, H.J.S. 1964. An analysis of milk production in shorthorn Zebu herd at Entebbe. Trop. Agric. 41:15-19.
Matlon, P. 1987. The West African semi-arid tropics. *In* J. Mellor et al. (ed) Accelerating food production in sub-Saharan Africa. Johns Hopkins Univ. Press, Baltimore MD.
McNeely, J.A. (ed) 2001. The great reshuffling: Human dimensions of invasive alien species. IUCN, Gland, Switzerland and Cambridge, UK.
Mengesha, M.H., and S.A. Rao. 1991. Status and diversity of African germplasm collections maintained at ICRISAT. *In* Crop genetic resources of Africa. Proc. Int. Conf. Nairobi, 26-30 Sept 1988. IBPGR, UNEP, IITA, CNR, Nairobi.
Menkir, A., and Y. Kebede. 1984. High rainfall, intermediate altitude sorghum. Sorghum Newsl. 27:3-4.
Minja, M.M.J. 1994. Medicinal plants used in the promotion of animal health in Tanzania. Office Int. des Epizooties, Revue, Scientifique Technique, 13:3.
Minja, M.M.J., and R.D. Allport. 2001. Ethnoveterinary knowledge practiced by Maasai in Simanjiro district northern Tanzania: Ethnoveterinary knowledge project. Ministry of water and livestock development/VETAID, Tanzania.
Morrison, W.I., M. Murray, and W.I.M. McIntyre. 1981. Bovine trypanosomiasis. M. Ristic and I. McIntyre (ed) Diseases of cattle in the tropics. Martinus Nijhoff Publ., the Hague.
Mortimore, M., and M. Tiffen. 1995. Population and environment in time

perspective: The Machakos story. p. 69-90. T. Binns (ed) Population and environment in Africa. Wiley, Chichester.

Moyo, S., and P. Yeros. 2005. Resurgence of social movements. S. Moyo and P. Yeros (ed) Reclaiming the land: The resurgence of rural movements in Africa, Asia and Latin America. Zed Books, London.

Moyo, S. 2005. Land question and land reform in southern Africa. Presentation at RSA Land Summit, Soweto, 28 Sep-1 Aug 2005.

Msechu, J.K.K., S.M. Das, and D.B. Mpiri. 1987. Improvement of zebu cattle productivity through breeding. TSAP Proc. 14:1-22.

Muchena, P. 1994. Implications of climate change for maize yields in Zimbabwe. Implications of climate change for international agriculture: Crop modeling study. EPA, Washington DC.

Mukanda, N., and R. Mwiinga. 1993. Soil and water management in Zambia. p. 37-40. N. Hudson and R. Cheatle (ed) Working with farmers for better land husbandry. IT Publ., London.

Muleba, N., and H.C. Ezumah. 1985. Optimizing cultural practices for cowpea in Africa p. 289-295. *In* S.R. Singh, and K.O. Rachie (ed) Cowpea research, production and utilization. John Wiley, UK.

Muntemba, S., and C.M. Blackden. 2000. Gender and poverty in Africa. Conf. on Poverty Alleviation in Africa, Nairobi, 6-10 Mar 2000. CAPA/World Bank, Washington DC.

Murwira, H. K., M.J. Swift, and P.G.H. Frost. 1995. Manure as a key resource in sustainable agriculture. p. 131-148. J.M. Powell et al. (ed) Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa II. ILCA, Addis Ababa.

Musahara, H., and C. Huggins. 2005. Land reform, land scarcity and post-conflict reconstruction: A case study of Rwanda. p. 269-346. *In* C. Huggins and J. Clover (ed) From the ground: Land rights, conflict and peace in sub-Saharan Africa. Inst. Security Studies, African Centre Tech. Studies, Nairobi.

Musibono, D.E. 1992. Qualite de l'Eau et Aquaculture: Une approche d'Ecodeveloppement. (In French). MTD Engineering, Kinshasa.

Musibono, D.E., and K. Mbale. 1995. Notes préliminaires sur une plante aquatique tropicale, Hydrocharis chevalieri (DeWild) Dandy, à potentialités socio-économiques (In French). Annales Fac. Sci. UNIKIS, Kisangani, Zaire.

Myers, N. 1986. Tackling extinction of species: A great creative challenge. Albright lecture, Univ. California, Berkeley.

Myers, N. 1988. Tropical forests and their species: Going, going . . . ? p. 28-34. E.O. Wilson (ed) Biodiversity. Nat. Acad. Press, Washington DC.

Nakimbugwe, H., J. Solkner, and A. Williams. 2004. Open nucleus cattle breeding program in the Lake Victoria crescent region of Uganda. Proc. Conf. Rural Poverty Reduction Research and Development. Trans. Deutscher Tropentag, Berlin. 5-7 Oct 2004. Humboldt Univ., Berlin.

Ndlovu, L.R., and P.H. Mugabe. 2002. Nutrient cycling in integrated plant-animal systems: Implications for animal management strategies in smallholder farming systems. C.B. Barrett et al. (ed) Natural resources management in African agriculture: Understanding and improving current practices. CAB Int., UK.

NEPAD. 2003. Comprehensive African agriculture development program. Available at www.nepad.org/2005/files/documents/caadp.pdf. NEPAD Secretariat, African Union, Nairobi.

Nestle, B. 1984. Animal production systems in different regions. p. 131-140. B. Nestle (ed) World animal science: Development of animal production systems. Elsevier, Amsterdam.

Neuenschwander, P. 1993. Human interactions in classical biological control of cassava and mango mealybugs on subsistence farms in tropical Africa. p. 143-177. *In* M.A. Altieri (ed) Crop protection strategies for subsistence farmers. Westview Press, Boulder.

Neuenschwander, P., C. Borgemeister, and J. Langewald. 2003. Biological control in IPM Systems in Africa. CABI Publ., UK.

Norval, R.A.I., B.D. Perry, and A.S. Young. 1992. The epidemiology of Theileriosis in Africa. Academic Press, London.

NRC (National Research Council). 1979. Tropical legumes: Resources for the future. Nat. Acad. Sci., Washington DC.

NRC (National Research Council). 2004. Biological confinement of genetically engineered organisms. Nat. Acad. Press, Washington DC.

Ntare, B.R., F. Waliyar, M. Ramouch, E. Masters, and J. Ndjeunga (ed) 2005. Market prospects for groundnut in West Africa? CFC Tech. ICRISAT, India.

Ntiamoa-Baidu, Y. 1997. Wildlife and food security in Africa: FAO conservation guide. FAO, Rome.

Ogutu, J.O., N. Bhola, and R. Reid. 2005. The effects of pastoralism on the density and distribution of carnivores and their prey in the Mara ecosystems of Kenya. J. Zoology 265:281-293.

OIE (World Organization for Animal Health). 2007. Rinderpest. Available at http://www.oie.int/eng/info/en_peste.htm. OIE, Paris.

Okoli, O.O. 1991. Yam germplasm diversity, uses and prospects for crop improvement in Africa. p. 109-117. *In* Crop genetic resources of Africa. Proc. Int. Conf. Nairobi, 26-30 Sept. 1988. IBPGR, UNEP, IITA, CNR, Nairobi.

Olubayo, F.M., and G.R. Port. 1997. The efficacy of harvest time modification and intercropping as methods of reducing the field infestation of cowpeas by storage bruchids in Kenya. J. Stored Prod. Res. 33:271-276.

Ostrom, E. 2000. Collective action and the evolution of social norms. J. Econ. Perspec. 14:137-158.

Owen, E. 2005. Introduction: The need to change the "mind-set". p. 1-11. E. Owen et al. (ed) Livestock and wealth creation: Improving the husbandry of animals kept by resources-poor people in developing countries. Nottingham Univ. Press, UK.

Owusu, N., M.P. Jones, and B.N. Singh. 1999. Genetic of tolerance for iron toxicity in rice. Res. Notes. IRRI, Manila.

Pala, A.O. 1976. African women in rural development: Research priorities. Am. Council Educ., Washington DC.

Pala, A.O. 1983. Women's access to land and their role in agriculture and decision-making on the farm: Experiences of the Juluo of Kenya. J. Eastern Africa. Res. Dev. 13:69-85.

Paling, R.W., and R.H. Dwinger. 1993. Potential of trypanotolerance as a contribution to sustainable livestock production in tsetse affected Africa. Vet. Q. 50:60-67.

PAN Africa. 1999. Réglementation des pesticides dangereux au Sénégal. (In French). Monitoring & Briefing 4, Pesticide Action Network, Dakar.

PAN Africa. 2000. Regulation of dangerous pesticides in Ghana. Monitoring & Briefing 5, Pesticide Action Network, Dakar.

PAN Asia and the Pacific. 1999. Warning: Pesticides are dangerous to your health! Stop endocrine disrupting chemicals. Pesticide Action Network, Penang.

Pankhurst, D., and S. Jacobs. 1988. Land tenure, gender relations and agricultural production: The case of Zimbabwe's peasantry. *In* J. Davison (ed) Agriculture, women and land: The African experience. Westview Press, Boulder.

Payne, W.J.A. 1990. An introduction to animal husbandry in the tropics. 4th ed. Longmans, UK.

Persley, G. 1990. Biosafety in agricultural technology. p. 345-352. Biotechnology: Enhancing research on tropical crops in Africa. CTA and IITA, Ibadan.

Phuthego, T.C., and R. Chanda. 2004. Traditional ecological knowledge and community based natural resources management: Lessons from a Botswana wildlife management area. Appl. Geography 24:57-76.

Pottier, J. 2005. Customary land tenure in sub-Saharan Africa today: Meaning and contexts. p. 55-75. *In* C. Huggins and J. Clover (ed) From the ground: Land rights, conflict and peace in sub-Saharan Africa. African Centre for Technology Studies, Nairobi and Inst. Security Studies, Pretoria.

Prins, H.H.T. 1992. The pastoral road to extinction: Competition between wildlife and traditional pastoralism in East Africa. Environ. Conserv. 71:107-110.

Pritchard, J.M. 1979. Africa: A study of geography for advanced students. 3rd ed. Longman, London.

Pullin, A. 2004. Conservation biology. Cambridge Univ. Press, UK.

Rachmeler, D. 2003. Trip report: Water hyacinth infestation at the Inga dam, Bas Congo, DRC. Innovative Resource Manage., Washington DC.

Raup, D.M., and J.J. Sepkosky. 1984. Periodicity of extinction in the geological past. PNAS 81:801-805.

Raven, P.H. 1987. We are killing our world. Pres. Conf. AAAS. Chicago. Feb 1987. Missouri Bot. Garden, St. Louis.

Reid, R.S., and J.E. Ellis. 1995. Livestock-mediated tree regeneration: Impacts of pastoralists on dry tropical woodlands. Ecol. Appl. 5:978-992.

Reij, C. 1996. Evolution et impacts des techniques de conservation des eaux et des sols. (In French). Centre for Development Cooperation Services, Vrije Univeriseit, Amsterdam.

Reilly, B.K., E.A. Sutherland, and V. Harley. 2003. The nature and extent of wildlife ranching in Gauteng province, South Africa. S. Afr. J. Wildlife Res. 32(2):141-144.

Riise, J.C., A. Permin, and K.N. Kryger. 2005. Strategies for developing family poultry production at village level: Experiences from West Africa and Asia. World Poul. Sci. J. 61:15-22.

Roberts, T.R. 1975. Geographical distribution of African freshwater fishes. Zool. J. Linn. Soc. 57:249-319.

Roose, E. 1994. Introduction à la gestion conservatoire de l'eau, de la biomasse et de la fertilité des sols (GCES). (In French). Bull. 70. FAO, Rome.

Ruthenberg, H. 1980. Farming systems in the tropics. Clarendon Press, UK.

Saito, K., and C.J. Weidemann. 1990. Agricultural extension for women farmers in Africa. Disc. Pap. 103. World Bank, Washington DC.

Saito, K., and D. Spurling, and W. Zijp. 1992. Designing and implementing agricultural extension for women farmers. Tech. notes. World Bank, Washington DC.

Sakaguchi, M., H. Nakamura, K. Sonoda, F. Hamada, and K. Hirai. 1996. Protection of chicken from Newcastle disease by vaccination with a kinear plasmid DNA expressing the F protein of Newcastle disease virus. Vaccine 14:747-752.

Sanchez, P.A., K.D. Shepherd, M.J. Soule, F.M. Place, R.J. Buresh, and A-M. Izac. 1997. Soil fertility replenishment in Africa: An investment in natural resource capital. p. 1-46. *In* R.J. Buresh et al. (ed) Replenishing soil fertility in Africa. Soil Sci. Soc. Am. Spec. Publ. 51. Madison WI.

Sanders, J.H., B.I. Shapiro and S. Ramaswamy. 1996. The economics of agricultural technology development in sub-Saharan Africa. John Hopkins Univ. Press, Baltimore MD.

Sandford, S. 1983. Management of pastoral development in the third world. John Wiley, UK.

Schilling, R., and S.M. Misari. 1992. Assessment of research achievements in the savanna regions of West Africa. p. 97-112. *In* Groundnut: A global perspective. Proc. Int. Workshop, Patancheru, India. 25-29 Nov. 1991. ICRISAT, Niamey.

Scoones, I. 1989. Economic and ecological carrying capacity: Implications for livestock development in Zimbabwe's communal areas. Pastoral Dev. Network Pap. 27b. ODI, London.

Scoones, I. 1992. Coping with drought: Responses of herders and livestock in contrasting savanna environments in southern Zimbabwe. Human Ecol. 20:293-314.

Scoones, I. 1995. Exploiting heterogeneity: Habitat use by cattle in the communal areas of Zimbabwe. J. Arid Environ. 29:221-237.

Sere, C., and H. Steinfeld. 1996. World livestock productions systems: Current status, issues and trends. Anim. Prod. Health Pap. 127. FAO, Rome.

Shapiro, B. 1994. Nutrition effects of crossbred cow adoption in Debre Berhan. ILCA, Addis Ababa.

Sharma, H.C., and K.F. Nwanze. 1997. Insect pests of sorghum: Biology, extent of losses and economic threshold. p. 9-23. *In* H.C. Sharma et al. (ed) Plant resistance to insects in sorghum. ICRISAT, India.

Shumway, C.A., D. Musibono, S. Ifuta, J. Sullivan, R. Schelly, J. Punga et al. 2002. Biodiversity survey: Systematics, ecology and conservation along the Congo River. Res. Report. USAID, Washington DC.

Simons, A.J., and R.R.B. Leakey. 2004. Tree domestication in tropical agroforestry. Agrofor. Syst. 61:167-181.

Sindiga, I., N. Chacha, and M.P. Kanunah (ed) 1995. Traditional medicine in Africa. East African Educ. Publ., Nairobi.

Singh, S.R., L.E.N. Jackai, G. Thotthapilly, K.F. Cardwell, and G.O. Myers. 1992. Status of research on constraints to cowpea production. p. 21-26. Biotechnology: Enhancing research on tropical crops in Africa. CTA. IITA, Ibadan.

Singh, B.B., and H.A. Ajeigbe. 2002. Improving cowpea-cereals based cropping systems in the dry savannas of West Africa p. 278-286. *In* C.A. Fatokun et al. (ed) Challenges and opportunities for enhancing sustainable cowpea production. IITA, Ibadan.

Skonhoft, A. 1998. Resource utilization, property rights and welfare: Wildlife and the local people. Ecol. Econ. 26(1):67-80.

Skonhoft, A., and J.T. Solstad. 1998. Investing in wildlife pay its way? J. Afr. Econ. 7:237-262.

Smale, M., and P.W. Heisey. 1994. Maize research in Malawi revisited: An emerging success story? J. Int. Dev. 6:689-706.

Smaling, E.M.A., S.M. Nandwa, and B.H. Janssen. 1997. Soil fertility in Africa is at stake. R.J. Buresh et al. (ed) Replenishing soil fertility in Africa. Soil Sci. Soc. Am. Spec. Publ. 51. Madison WI.

Spencer, D.C.S., P.J. Matlon, and H. Loffler. 2004. African agricultural production and productivity in perspective. Background Pap. 1: Study panel on science and technology strategies for improving agricultural productivity and food security in Africa. IAC, Netherlands.

Staal, S.J., M. Owango, H. Muriuki, M. Kenyanjui, D. Njubi, F. Musembi et al. 2001. Dairy systems characterization of the Nairobi milk shed: Application of spatial and household analysis. KARI, MoARD, ILRI, Nairobi.

Steiner, K.G. 1996. Causes of soil degradation and development approaches to sustainable soil management. Margraf Verlag Publ., Germany.

Sterner, T. 2003. Policy instrument for environmental and natural resource management. Resources for the Future, Washington DC.

Stiassny, M.L.J. 1996. An overview of freshwater biodiversity with some lessons from African fishFisheries 21(9):7-13.

Stocking, M. 1985. Soil conservation policy in colonial Africa. Agric. Hist. 59:148-161.

Stoorvogel J.J., and E.M.A. Smaling. 1990. Assessment of soil nutrient depletion in sub-Saharan Africa: 1983–2000. Vols. 1-4. Winand Staring Centre, Wageningen.

Swift, J. 1988.Major issues in pastoral development with special emphasis on selected African countries. FAO, Rome.

Swift, J. 1996. Sustainable management of the soil resources: Developing a framework for research and development. World Bank, Washington DC.

Thibault, M., and S. Balney. 2003. The oil Industry as an underlying factor in the bushmeat crisis in central Africa. Conserv. Biol. 17(6):1807-1813.

Tiffen, M., M. Mortimore, and F. Gichuki. 1994. More people, less erosion: Environmental recovery in Kenya. John Wiley, Chichester.

Ton, P., S. Tovignan, and S.D. Vodouhe. 2000. Endosulfan deaths and poisonings in Benin. Pesticides News 47:12-14. Pesticide Action Network, UK.

Twongo, T. 1995. Impact of fish species introductions on the tilapias of Lakes Victoria and Kyoga. p. 45-57. T.J. Pitcher, and P.J.B. Hart (ed) The impacts of species changes in African lakes. Fish Fisheries Ser. 18. Chapman and Hall, UK.

Ukeje, E. 2004. Modernizing small holder agriculture to ensure food security and gender empowerment. Available at http://www.g24.org/ukeje.pdf. Intergov. Group of Twenty-Four. Washington DC.

UNDP. 1996. Urban agriculture, food, jobs and sustainable cities. UNDP, New York.
UNDP. 2000. Bioenergy primer: Modernized biomass energy for sustainable development. UNDP, New York.
UNFPA. 2007. Overview: Sub-Saharan Africa. Available at http://www.unfpa.org/profile/africa_overview.htm. UN Population Fund, New York.
UNHCR. 2004. Rapid environmental assessment in the D.R. Congo: Annual technical report. UNHCR, Kinshasa.
UNHCR. 2005. Rapid environment assessment in the D.R. Congo: Annual technical report. UNHCR, Kinshasa.
Uphoff, N., S. Rafaralaby, and J. Rabenandrasana. 2002. What is the system of rice intensification? Available at http://www.foodsecurity.gov.kh/sri/documents/reports/633-What%20is%20SRI.pdf. CIIFAAD, Cornell Univ., NY.
Van der Pol, F. 1992. Soil mining: An unseen contributor to farm income in southern Mali. Bull. 325. Royal Trop. Inst., Amsterdam.
Van Ek, G.A., J. Henriet, S.F. Blade, and B.B. Singh. 1997. Quantitative assessment of traditional cropping systems in the Sudan savanna of northern Nigeria II: Management of productivity of major cropping systems. Samaru J. Agric. Res. 14:47-60.
Van Noordwijk, M., G. Cadish, and C.K. Ong (ed) 2004. Below-ground Interactions in tropical agroecosystems: Concepts and models with multiple plant components. World Agroforestry Centre, CABI Publ., Nairobi.
Wambura, P. N., A.M. Kapaga, and J.M. Hyera. 2000. Experimental trials with a thermal stable Newcastle disease virus (strain I_2) in commercial and village chicken in Tanzania. Prev. Vet. Med. 43:75-83.
Wambwa, E. 2003. Diseases of importance at the wildlife/livestock interface in Kenya. Proc. S. and E. African expert panel on designing successful conservation and development interventions for wildlife/livestock interface. AHEAD Forum, IUCN 5th World Parks Congress, Durban, 14-15 Sept 2003.
Wanyama, J.B. 1997. Confidently used ethnoveterinary knowledge among pastoralists of Samburu, Kenya. Intermediate Tech., Kenya.
WARDA. 2003. Strategic plan 2003-2012. Available at http://www/warda.org. Cotonou, Benin.
WARDA. 2005a. Medium term plan 2006-2008. Available at http://www .warda.org. Africa Rice Center (WARDA), Cotonou.
WARDA. 2005b. Rice trends in sub-Saharan Africa. Available at http://www.warda.org/publications/Rice%20Trends.pdf. Africa Rice Center (WARDA), Cotonou.
White, M.N. 1959. A survey of African land tenure in northern Rhodesia. p.174-178. *In* J. Afr. Admin. 11:4.
Whitlow, J.R. 1988a. Soil conservation history in Zimbabwe. p. 299-303. J. Soil Water Conserv. 43:4.
Whittingham E., J. Campbell, and P. Townsley. 2003. Poverty and coral reefs: Vol. 1-2. UNESCO, Paris.
WHO. 2002. The world health report 2002: Reducing risks, promoting healthy lives. WHO, Geneva.
Willadsen, P. 2002. Anti-tick vaccines. Parasitology 129:S1-S21.
Williamson, M. 1996. Biological invasions. Chapman and Hall, UK.
Williamson, S. 2003. The dependency syndrome: Pesticide use by African smallholders. Pesticide Action Network, UK.
Wilson, E.O. 1988. The current state of biological diversity. p. 3-17 E.O. Wilson (ed) Biodiversity. National Acad. Press, Washington DC.
Wilson, R.T. 1995. Livestock production systems. Macmillan Education, London and CTA, Wageningen.
Wilson, R.T. 2003. The environmental ecology of oxen used for draught power. Agric. Ecosyst. Environ. 97:21-37.
Wilson, R.T., P.N. de Leeuw, and C. de Haan. 1983. Recherchés sur less systems en zones arides: Result preliminaries (Rapport de recherché No. 5 (In French) ILCA, Addis Ababa.
Wilson, T., A. Pearson, N. Bradbear, A. Jayasuriya, H. Laswai, L. Mtenga et al. 2005. Livestock products: valuable and more valuable. E. Owens et al (ed) Livestock and wealth creation: Improving the husbandry of animals kept by resource—poor people in developing countries. Nottingham Univ. Press, UK.
World Bank. 1997. World development indicators. World Bank, Washington DC.
World Bank. 2004. Renewable energy for development: The role of the World Bank Group. World Bank, Washington DC.
World Bank. 2006. World development indicators. Available at http://devdata.worldbank.org/wdi2006/contents/cover.htm. World Bank, Washington, DC.
World Watch Institute. 2006. Biofuels for transportation: Global potential and implications for sustainable agriculture and energy in the 21st Century. World Watch Inst., Washington DC.
WRI. 1994. World resources 1994-95 A guide to the global environment. Oxford Univ. Press, New York.
WRI. 1998. The watersheds of the world. WRI, Washington DC.
WRI. 2002. World resources report 2001-2002. WRI, Washington DC.
Yudelman, M. 1994. Demand and supply of foodstuffs up to 2050 with special reference to irrigation. *In* Feeding the world: Issues and challenges for irrigated agriculture in the 21st century. IWMI, Sri Lanka.
Zuidberg, L. 1994. Integrated rural development: For whom and with whom? p. 49-70. V. Gianotten et al. (ed) Assessing the gender impact of development projects. Royal Trop. Inst., Amsterdam.
Zwartz, J.A., and J.A.J. Hautvast. 1979. Food supply, nutrition and plant breeding. p. 1-44. Plant breeding perspectives: Centennial publication. Konionklijk Kweekbedrijf en Zaadhandel D.J. van der Have Centre Agric. Publ. Documentation, Wageningen.

3

AKST: Generation, Access, Adaptation, Adoption and Effectiveness

Coordinating Lead Authors:
Yalemtsehay Mekonnen (Ethiopia), Idah Sithole-Niang (Zimbabwe), Felix Fiadjoe (Ghana)

Lead Authors:
Roshan Abdallah (Tanzania), Agnes Abera-Kalibata (Rwanda), Francis Gichuki (Kenya), Marnus Gouse (South Africa), Harry Palmier (France), Wahida Patwa Shah (Kenya), Stacey J. Young (USA)

Contributing Authors:
Apophia Atukunda (Uganda), Mohamed Bakarr (Kenya), David Knopp (USA)

Review Editors:
Moctar Toure (Senegal)

Key Messages

1. Agriculture's contribution to economic development and to achieving development and sustainability goals in SSA is undermined by high population growth rates, high dependency ratios, disease, marginalization of women and inadequate investment in agricultural education. The population that is economically active is as low as 24% in some countries. Disease also affects overall economic growth. The three major killers, malaria, tuberculosis and HIV/AIDS, have reduced the available workforce in agriculture and other sectors.

2. In formal AKST, women are marginalized. Their disempowerment compromises household nutrition and food security and negatively affects their ability to improve agricultural production. In addition, the impact of HIV/AIDS on women is significant and poses acute consequences for food security. They are affected directly, as they fall ill, and indirectly, as they care for ill relatives or their orphans.

3. External funding for agricultural research and development continues to eclipse national investment. Curbs on government expenditure and waning support for agriculture and agricultural research and development (R&D) have characterized the past two decades. In the 1990s, spending in agricultural R&D declined 2.5% annually except in Nigeria and South Africa.

4. Current investments in agricultural education are inadequate to provide for well-trained researchers, agricultural engineers, extension agents and other specialists. Increased investments in human resources are critical for developing an effective and sustainable agricultural sector. Insufficient resources for agricultural R&D and its application to agricultural production are significant constraints and threaten the ability of AKST to contribute to development goals.

5. The effectiveness of AKST is compromised by a lack of institutional coordination. Universities, research institutions, extension facilities, private businesses and other stakeholders often operate independently. The lack of coordination among organizational bodies undermines the feedback loops necessary for developing a responsive research agenda and compromises access to knowledge. Opportunities to promote national, regional and international collaboration are lost because of lack of coordination. Collaboration between national agricultural research systems (NARS), subregional organizations, and international research and development partners is an important component of AKST. The Consultative Group for International Agricultural Research (CGIAR) programs such as ecoregional initiatives, challenge programs, and the development of subregional action plans are good examples of collaborative approaches. They are refined and expanded through NEPAD/FARA (New Partnership for Africa's Development/Forum for Agricultural Research in Africa) initiatives and programs.

6. Appropriate laws, institutions and market mechanisms are required for advances in agricultural technologies such as irrigation, improved seeds, genetically modified (GM) crops and fertilizer. Institutional capacity includes supervision, upstream inputs, microfinance and credit, markets, consumer feedback, and policies to regulate technologies and their ownership. Without this capacity, farmers will remain unwilling to invest in new technology, and returns will be limited. Most countries in SSA did not benefit from the Green Revolution, partly due to from lack of infrastructure, microfinance, credit, markets and regulating policies. Private businesses will not invest where these structures are limited or questionable.

7. Agriculture in SSA is increasingly vulnerable to water scarcity, climate change and land degradation, leading to low productivity and the loss of biodiversity. Unlike the rest of the world, agricultural yields in SSA have not increased over the past five decades. The underlying reasons include water scarcity, climate, limited institutional capacity and access to markets, resource degradation and a loss of agrobiodiversity. Approximately 80% of the irrigation potential in SSA is untapped and as much as 40-70% of irrigation is ineffective. These factors prohibit the use of fertilizer and higher yielding crop and livestock varieties. The capacity of water management organizations to maximize the benefits from irrigation, supervise equitable water distribution and use, and protect downstream ecosystems is inadequate.

8. The poor, who have the least capacity to adapt, are the most vulnerable to climate change. Their resilience is undermined by fragile ecosystems, weak institutions, ineffective governance and poverty. Although SSA produces the lowest percentage of greenhouse gases per capita worldwide, the region will be disproportionately affected by changes in climate over the long term. It is projected that the areas hardest hit by climate change will be the West African Sahel, rangelands, the Great Lakes, coastal areas of eastern Africa and the drier zones of southern Africa. Deforestation and land use changes limit the sustainability of agriculture by diminishing the supply of groundwater and seasonal surface water in semiarid areas.

9. Agricultural practices in SSA deplete nutrients from the soil. Organic and inorganic inputs are required to achieve higher yields, yet application rates remain low. In many parts of SSA, access to inorganic fertilizers remains low because of undeveloped marketing and distribution systems.

10. Locally generated and holistic approaches to agriculture that concurrently address production, profitability, economic development, natural resource conservation and human well-being are more effective than strategies that address these issues in isolation. Integrated approaches can advance AKST by increasing local knowledge and capacity, enhancing products and services, and more effectively evaluating options for agricultural practices.

11. The safety and economic risks posed by genetically modified organisms (GMOs) are not yet well under-

stood. Countries have responded by developing biosafety policies and adhering to international agreements such as the Cartagena Protocol. Education on biosafety issues related to GMO testing is helping to address problems of risk assessment and management and strengthening regional policies and capacity.

12. Inadequate local trade, sporadic regional integration and inefficient market conditions adversely affect agriculture profits, investments and effective application of agricultural innovation. From 1980 to 2000, agricultural exports from SSA stagnated at 2% of the global market due to poor infrastructure, low production, noncompetitive, unskilled labor and heavy tariffs in external markets. Lack of credit and investment to expand agricultural production also contribute to low export figures.

13. Inadequate infrastructure for transportation and food processing, irrigation and information and communications technology (ICT) impede the effectiveness of formal AKST. These inadequacies result in lost economic opportunities for farmers and food industries. For example, the lack of food processing and storage facilities close to agricultural areas results in high input costs and low farm profits. This reduces the incentive for farmers to apply agricultural innovation and inhibits them from adopting market-oriented production approaches.

14. The development and use of ICT has the potential to increase access to formal and informal AKST, but realization of this potential has been uneven. Some countries in SSA have limited access to ICT because of restrictive policies, investment barriers, limited ICT coverage and socioeconomic barriers to Internet use. Disputes arising from cable ownership, fees and infrastructure threaten widespread access to the Internet.

3.1 Human Context

3.1.1 Human health and nutrition

Disease affects the availability of labor in SSA, particularly in the agricultural sector. With the exception of HIV/AIDS, the most significant diseases are water-borne: malaria, schistosomiasis and typhoid; others include onchocerciasis, cholera, dengue fever and guinea worm (UNESCO, 2003). The incidence of disease is high during the rainy season when farming activities peak, thus lowering food production and availability and overall food security.

Malaria. The death burden from malaria is 15% in sub-Saharan Africa (Foster and Phillips, 1998), higher than in any other area of the tropics (Kiszewski and Teklehaymanot, 2004). Those most affected are women of reproductive age and children. In Africa, one in five childhood deaths is attributable to malaria (WHO, 2007). High malnutrition rates tend to increase child mortality from malaria.

Malaria epidemics are associated with wet seasons (that is pre-harvest) when household incomes are low (Malaney et al., 2004). Some environmental changes brought about by agricultural development have created more breeding grounds for the vector mosquito (Malakooti et al., 1998).

HIV/AIDS pandemic. An estimated 22.5 million people were living with AIDS in 2007 (AVERT, 2007), most of them residing in communities already suffering from poverty, malnutrition and other diseases. In infected individuals, HIV affects and is affected by nutrition. The consequences of HIV infection include reduced ability to absorb nutrients from food, changes in metabolism and a reduction in food intake due to HIV-related symptoms. Poor nutrition increases the vulnerability to, and the severity of opportunistic infections. It can also reduce the beneficial effects of medication and can accelerate the progression of the disease. The AIDS pandemic has serious implications for rural agricultural production and household food security, and is closely tied to gender concerns and policies (Du Guerny, 1999).

The impact of HIV/AIDS on agricultural production is observed through declining yields due to sickness and dependency on outside labor; reduction in land under cultivation; decline in crop variety, inputs and livestock production; and loss of local agricultural knowledge and skills because of the loss of knowledgeable family members. Food consumption among household survivors often declines after an adult member dies and the incidence of stunting increases among orphans. Household food security is frequently lower because of fostering children and caring for sick relatives (AVERT, 2007). Where land tenure and inheritance traditions favor males, the effect of HIV/AIDS on agriculture may be especially acute. Increased numbers of widowed women, whose right to land is already constrained by traditional inheritance customs, may lead to more land left uncultivated. All of these situations challenge economies that depend on agriculture (Mesko et al., 2003).

Impact of HIV/AIDS on agricultural labor with respect to gender. Research conducted in Kenya shows that households experience a 68% decline in food production following the death of a male household head (USAID, 2003). Though women are largely responsible for agriculture production, household changes occur as the male head of household's health declines. To cope with the financial burden of AIDS, assets are sold, loans go into default, household collateral decreases and the AIDS-affected households are deemed not creditworthy. In addition, there is a shift from cash to subsistence crops during the household head's illness as the family copes with the financial burden of AIDS. Upon the death of a male head of household, it is often impossible to resume cash crop production because the cash investment for inputs is no longer available.

In some places, following the death of the male head of household, relatives of the deceased may seize property from the widow, causing a decline in agricultural production. A study in Namibia found that 44% of widows lost cattle, 28% lost small livestock and 41% lost farm equipment through disputes with in-laws after the death of an HIV-infected husband (FAO, 1996). The effect on overall agricultural production may be nil if the resources seized from the household are in use elsewhere; however, the effect on the widow's household can be severe.

Because women bear much of the responsibility for household food security, the impact of HIV/AIDS on women has acute consequences for other family members and for transmitting agricultural knowledge across generations. The disproportionate effect of HIV/AIDS on women intersects with their greater responsibility for agricultural production and results in decreased labor available for agriculture when women fall ill or care for others who fall ill. Also, women from AIDS-infected households are less able than others to adopt innovations from advances in AKST. As the agricultural labor pool decreases, households retreat from cash crop production and resort to low-labor staples, often root vegetables of inadequate nutritional value. Relying on staple foods decreases household income and further stretches labor and other resources.

The effects of HIV/AIDS on agriculture are visible throughout SSA. In Uganda, for instance, AIDS-affected households in mixed agriculture, fisheries and pastoral sectors are producing less. In Zambia, AIDS-related deaths among the productive population have led to an increase in orphaned children, which places an additional burden on the community. In Uganda's Rakai District, herd sizes have tended to decrease. Rising rates of HIV in pastoral communities are being reported in Kenya around Lake Turkana and in southern Sudan (IRIN, 2006).

Impact on agricultural extension services. Agricultural extension workers play a pivotal role in adopting and transmitting AKST. As workers spend fewer hours on the job due to illness, extension services are curtailed. A local extension officer in Uganda noted that between 20 and 50% of total work time was lost as a result of HIV/AIDS. Staff members were frequently absent from work, attending funerals and caring for sick relatives (FAO, 1994). In eastern and southern Africa, HIV and AIDS have resulted in a high number of deaths of skilled workers, whose replacement will take time (Jayne et al., 2004).

The loss of agricultural knowledge and management skills. When one or both parents die or are seriously ill, their skills may not be transferred to their children or other relatives. This may have far-reaching implications for agricultural production. In areas where the incidence of HIV and AIDS is high and agricultural skills are lacking, farming is often neglected and yields are poor.

The consequences of HIV/AIDS on rural populations and agricultural systems include the threat to household and community food security; a decline in the nutrition and health of small-scale producers and their families; a decline in educational status, as children are forced to leave school; and changes in social structures, as households adapt to the break-up of families, to the growing incidence of female-headed households, and to the increasing number of orphans and rural poor. The impact of the pandemic is also likely to be severest among already vulnerable populations such as those who are malnourished.

Pesticides. Health hazards from chemical pesticides are a major source of concern. After decades of extensive chemical use in many SSA countries, the long-term effects on human health and the environment cannot be oversimplified. Since 1996 several studies of large-scale agricultural enterprises in Ethiopia show that agricultural workers have health problems caused by exposure to chemical pesticides (Lakew and Mekonnen, 1998; Mekonnen and Agonafir, 2002; Ejigu and Mekonnen, 2005). Studies of agricultural workers in Senegal (Abiola et al., 1988) and in Tanzania have reported unsafe pesticide handling (Ngowi et al., 2001). The environmental effects of these chemicals, however, have not been well studied.

3.1.2 Gender dynamics in AKST

Most women in sub-Saharan Africa bear multiple responsibilities: producing food; weeding and harvesting on men's fields; post-harvest processing; providing fuelwood and water; and maintaining the household. The burden on rural women is increasing as population growth outpaces the evolution and adoption of agricultural technology and as growing numbers of men leave farms for urban jobs. Women's marginalization within AKST and their overall burden and disproportionate responsibility in the household amplify their disempowerment and compromise household nutrition and food security. The vital role of women farmers requires measures to increase their managerial and technical capacity and to empower them to play a dynamic role in implementing future improvements (Dixon et al., 2001).

Women are typically marginalized at household, production and consumption levels. They are also marginalized at policy, market and institutional levels, with consequences for their households and communities. Women are usually responsible for agricultural production, but often are not empowered to make household decisions about labor and expenditures. Lower yields from farm plots controlled by women are usually the result of insufficient labor and inputs rather than poor management skills. Also, women are typically allocated land of poorer quality.

At the policy level. In some countries the state controls the land, while in others land can be owned privately. Land tenure laws, however, often favor men, sometimes even prohibiting women from owning land. This translates into a lack of collateral to obtain microfinance and credit, which could be used to hire labor, access new technologies, purchase inputs such as fertilizer and improved seed varieties, grow crops that require cash investments or buy land.

At the market level. A lack of access to microfinance and credit makes it harder for women to invest in agricultural inputs and tools that could increase yields. Typically, cash crops are seen as the province of men and it can be difficult for women to break into these markets. Access to markets, technology and practical information are keys to achieving development goals. Advances in information and communications technology, when provided to women, can be particularly effective in addressing gender issues (IAC, 2004).

At the organizational level. Women are not adequately represented among or served by agriculture extension. They represent only 3% of all agriculture extension agents in Africa (Brown et al., 1995). Women are also underrepresented in scientific research institutions, which may result in technology innovations that do not take into account women's roles in agricultural production. For example, new crop varieties that have higher yields are often not adopted because they require inputs that women typically cannot afford, or intensive management, which women cannot coordinate with other household responsibilities.

Agricultural production and household management leave women "time poor." The use of improved farm implements and appropriate mechanization can increase productivity, reduce drudgery, conserve labor and ensure timely farm operations while mitigating pressure on women. However, adoption of strategies that primarily benefit women may be inhibited by men, who have greater decision-making power.

Women are less likely than men to be able to afford agricultural technologies and farm inputs. They are less likely to make decisions within the household that would enable them to direct resources toward improvements. They are also less likely to control cash crop production, which often requires agricultural technologies and inputs, and often lack access to markets for cash crops as these markets are built on relationships among men. Women have less access to credit to invest in agricultural technologies and other farm inputs and they are more likely to spread household resources across a broader range of needs. While men may conceive of a choice among which agricultural technologies to use and which crops to apply them to, women may conceive of their choice as between acquiring technologies and paying school fees or medical bills.

3.1.3 Education, training and extension

Formal education in agriculture is available at all levels of the educational system in SSA, from primary school to tertiary institutions, and becomes more male-dominated at advanced levels. Students, however, do not seem to have much interest in extension education (Debouvry, 2001). Science students are more interested in studying medicine and engineering than agricultural science (World Bank, 2006). Formal education is almost universally conducted in official languages, certainly beyond the primary school level; thus, agricultural education is not conducted in African languages.

Extension training for future agents is inadequate, occupying a small percentage of the agricultural education curriculum. Inadequacies include a lack of instruction on effective communication in multilingual settings, and in speaking other local languages (Robinson, 1996). There are many types of extension work in SSA, the two main ones being commodity and general approaches. Under the commodity approach, commodity boards provide education and services to farmers who grow a cash crop, such as cocoa or tea, and the extension-to-farmer ratio is good. The major advantage to this approach is that the assistance provided includes inputs, marketing infrastructure and price guarantees. This assistance provides incentives for the farmer to adopt the technologies that are required for cash crop production.

In the general approach, the Ministry of Agriculture provides general extension services for all farmers. The extension agent-to-farmer ratio is usually inadequate because of inadequate recruitment and training of extension workers. The extension service emphasis is on farmer education, while other activities such as marketing are left to other organizations. Getting farmers to use agriculture technologies requires developed markets, adequate pricing and agricultural infrastructure. The general approach to extension services is mainly for staple food and animal producers, whose use of technology is relatively low.

Where the World Bank has intervened in the agriculture sector, training and visit (T&V) systems are used, which prescribe how and when an extension agent meets with a farmer and the kinds of interactions that should occur. T&V operates on the assumption that national agricultural research institutions (NARIs) and the international agricultural community provide appropriate and relevant technologies to disseminate to farmers. The number of farmers assigned to each extension agent is very high and as a result, most farmers do not receive educational services. This often has negative implications for the use of new technology. The T&V system has declined because of inadequate coordination with agricultural research systems, weak accountability, lack of political support, and above all, high recurrent costs leading to unsustainable services (Anderson et al., 2006).

Government investment in formal education in SSA has been increasing; however, the percentage of funds allocated to science and agriculture remains inadequate. Science and agriculture require much more investment to produce a relatively small number of graduates. The majority of graduates work with crops or plant-related fields, while few work in animal production, disease control and agricultural engineering (IAC, 2004).

Through donor-assisted programs, a number of scientists from SSA train outside the country. Some do not return after completing their studies. Even when scholars do return, they lack the research facilities and stimuli that enable them to work on par with their counterparts from the industrialized world. Those who do choose to work in their countries of origin often get absorbed into administrative jobs that have higher salaries, but curtails the continuity required to successfully complete research. Different donor-assisted programs attempt to address these obstacles. In west and central Africa, the International Foundation for Science and the French Research Institute for Development (IRD) provide competitive grants to junior researchers, in partnership with international scientists. They offer research expenses and scientific equipment, provided that the research is carried out in their country or region of origin.

In a bid to curb the loss of human resources, the Southern African Development Community (SADC) has developed a regional protocol to diminish competition from neighboring countries that attract professionals with higher salaries (SADC, 2007). African leaders have responded through various initiatives, such as establishing regional model research institutions that provide specialized scientific training. Some have instituted policies to attract scientists back to their countries of origin. Other factors that are important for retaining professionals include increasing teaching incentives, enhancing school infrastructure and revising teaching methods to increase student performance.

3.2 Key Actors and Institutional Arrangements

Between 1960 and 1980, overall economic growth in sub-Saharan Africa averaged 3.4% annually and agriculture contributed to economic growth in most countries. This growth was crucial for improving food and nutritional security. Major economic and social indicators began to show a decline in agricultural and industrial production and manufacturing by the end of 1970. The agricultural decline provoked massive food imports. These negative economic trends were exacerbated by adverse terms of trade, the oil crisis and the slump in the world economy. At the same time domestic problems, including civil strife and ethnic violence, threatened the stability of many sub-Saharan Africa states.

3.2.1 Investment and economic returns

Investments in agricultural R&D, particularly investments to develop risk-reducing and efficient technologies, are crucial determinants of agriculture growth. After years of relative neglect, agriculture has returned to the economic agenda of several African countries (World Bank, 2003). Increased production is the principal objective of public and private research in most SSA countries.

Roughly $1.5 billion (in 2000 international dollars) is spent annually on agricultural productivity programs in Africa. This figure includes public and private expenditures aggregated on national and global levels (Pardey et al., 2006). Much of this spending is concentrated in national programs, about half of which are financed by African governments, and the other half from external sources. A small proportion of the total is administered at the international level.

Returns on investments in agricultural research have generally been high (see Global Chapter 8), but in many countries research program productivity is low. The tendency is to support international and regional research, but innovations that reach farmers have not necessarily increased (Eicher, 2001).

International assistance has played a key role in agricultural research among developing countries, especially in Africa. Funding from loans and grants accounted for about 36% of total research expenditure in SSA in 2000. This was slightly lower the 43% in 1991 (Beintema and Stads, 2006). Analysts are particularly critical of the role of foreign assistance in Africa. Over the last two decades, critics have pointed to the high tolerance for defective institutions that produce little (FAO/SPAAR, 2002a). The decline in funding for agricultural research has prompted many NARS to give more attention to regional research, which uses available resources more efficiently. NARS are promoting collaborative work ranging from information exchanges to integrating research projects (FAO/SPAAR, 2002b).

3.2.2 National, regional and international actors

3.2.2.1 National actors and initiatives

Despite recognition of the important contribution agricultural research can make to economic growth and poverty reduction, Africa's national agricultural research and development institutions (NARS) face declining and unstable public funding. The efficiency and effectiveness of NARS have declined. Dependence on international donors has increased, but this funding remains largely unpredictable and highly variable across subsectors.

A recent study concluded that NARS lack the capacity to generate and maintain financial information; an imbalance exists between the goals of the NARS and the funding available to achieve these goals; government commitment to agricultural research has been cosmetic; and demand-driven research requires funding that addresses small-scale farmer concerns. The low percentage of representation of farmers and private businesses in NARI governance is of concern. Also of concern is sustainable financing; some governments deliver funds erratically and recruit only skilled human resources. NARS also lack consistent and high speed Internet capabilities.

Market-driven agriculture is placing new pressures on governments, communities and farmers to produce more for both domestic and international trade. National reforms remain vital for success, and the options for institutional reforms abound. Recently innovative national programs have supported agricultural organizations like those in Cote d'Ivoire (NASSP 2), Senegal (PSAOP) and Mali (PASAOP). They have strengthened relations between research and extension by promoting collaborative planning of research and development. For example, Cote d'Ivoire established Centre National de Recherche Agricole (CNRA), the first semi-private research institution in west and central Africa in 1997. A key feature of the center is the autonomy of leadership from direct government influence.

The National Agricultural Services Support Program (NASSP) was designed to provide appropriate agricultural services for farmers. NASSP 1 restructured the extension services, establishing a semi-private, demand-driven rural development agency, Agence Nationale du Développement Rural (ANADER). NASSP 2 created CNRA by merging two independent research centers, one working on forest humid zones and the other on savanna zones. CNRA decreased the number of staff members and offered higher salaries based on performance evaluation. Despite the recent political instability of Cote d'Ivoire, CNRA is an effective NARS implementing local and regional research using interdisciplinary methods in collaboration with international institutions. One of its more innovative features is a sustainable financing scheme from private investors. The financing objective is to provide 60% of capital assets and budgetary needs as the government contribution decreases to 20% of the total budget.

3.2.2.2 Regional actors and initiatives

In 1980, The Lagos Plan of Action called for food self-sufficiency (OAU, 1980). The Regional Food Plan for Africa (AFPLAN) responded to the African socioeconomic development crisis, advising governments to play a lead role in development because of the limited size and capacity of the private sector. Publicly funded programs responded by supporting agriculture research and extension, supplying fertilizer, and supporting export production and marketing and food distribution.

Collaboration in agricultural research has improved considerably in recent years because of the establishment of networks and regional coordinating bodies such as the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) and FARA. Much of the collaboration has been limited to information exchange, but potentially it will develop into regionally defined and country-specific research, provided that mutual trust can be established (Chema et al., 2003). The West Africa Agricultural Productivity Program (WAPP), as a pilot program under the Multi-Country Agricultural Productivity Program (MAPP) funded by the World Bank, supports this research orientation coordinated by CORAF/WECARD (West and Central African Council for Agricultural Research and Development) and FARA.

NEPAD adopted the Comprehensive Africa Agriculture Development Program (CAADP) to provide a strategic framework for agriculture reforms and investments for sustained development. CAADP's objective is 7% annual growth through the year 2015. Achieving this will require reforms to improve the policy and institutional environment of the agricultural sector, including greater efficiency in public expenditures for rural infrastructure and a significant increase in their budgets.

African agricultural research organizations like FARA work in a global network. FARA is the technical arm for NEPAD and conducts research on development strategies. This work requires coordinating the donor-supported activities of NARS by the CGIAR, by northern research institutions and universities, and by subregional bodies—ASARECA for East Africa, CORAF/WECARD for West and Central Africa and SADC Food, Agriculture and Natural Resources Directorate for southern Africa.

Inadequate coordination and planning of regional and national agricultural research and development are endemic in SSA (IAC, 2004). Synergies have not been exploited because of absent or weak links among national and regional research institutions and universities. In most cases, these institutions compete for funds and serve similar audiences. Collaboration needs to improve significantly among these institutions to take full advantage of the benefits from cooperation.

3.2.2.3 International actors and initiatives

Most of the international support for agriculture research in SSA has come from research institutions and specialized universities from former colonial countries rather than from the CGIAR. After independence in the 1960s, former colonial research stations in SSA devolved and northern research institutions and universities, such as the French Centre de Cooperation Internationale en Recherche Agronomique pour le Développement (CIRAD) and Institut de Recherche pour le Développement (IRD), initiated new partnerships with NARS. They focused on structured activities and predominantly invested in building national capacity.

From this background, collaborative planning, managing and training in regional research activities have emerged. French research institutions are actively engaged in combining specific NARS and northern agricultural and development programs with regional and international activities developed by International Agricultural Research Centers (IARCs) under the recently launched Challenge Programs coordinated by the CGIAR. In addition to creating a national research agency to fund domestic research, in 2005 France established the Inter-institutions and Universities Agency for Research on Development (AIRD), which operate through competitive bidding. Their goal is to increase research on development issues in collaboration with NARS, research institutions in France and universities in the South.

The CGIAR was created in 1971 to mobilize agricultural science institutions to reduce poverty, foster human well-being, promote agricultural growth and protect the environment. CGIAR comprises a strategic alliance of international and regional organizations and private foundations. Some recent examples of international agricultural research in SSA are drought-tolerant maize, the Africa Rice Center (WARDA) Nerica varieties, improved sorghum varieties (ICRISAT), improved tilapia for integrated aquaculture-agriculture (IITA), vitamin A-rich sweet potato (CIP), biological control of the cassava mealy bug, disease-resistant cassava varieties (CIAT/IITA), agroforestry (ICRAF) and control of trypanosomiasis in cattle (ILRI). Collaboration between the CGIAR and NARS can pose questions regarding ownership of research products.

By 2004, a small number of successful projects (5% of total CGIAR-NARS research investments in SSA), had recovered the cumulative 35-year investment of these institutions. Beyond 2004 the same successful projects could generate more than US$1.5 in benefits for every dollar invested (CGIAR Science Council, 2004).

Although CGIAR was behind the Green Revolution in Asia, it has not been able to achieve similar productivity increases in SSA. The causes are numerous, ranging from low use of irrigated farming, poor rural infrastructure, and inadequate local and regional markets. Despite some valuable achievements such as alley cropping, developed by ICRAF, and an agricultural research method developed by IITA, NARS remain relatively weak. Until the late 1980s, IARCs predominantly researched commodities that were not critical in SSA; they paid little attention to cassava, other roots and tubers, and pearl millet or to natural resource management (Diouf, 1989). Progress has been made but a number of donors question CGIAR's ability to adapt to the needs of NARS and to help in designing sustainable cropping systems, a cornerstone of rural development in SSA (Dore et al., 2006).

In response to criticism, the CGIAR established two task forces in 2003 to examine the program and structure of the CGIAR in Africa. They reported that the CGIAR lacked a vision in SSA, that their activities were not coordinated, and that competition for collaborators overburdened the NARS. Suggestions were made to consolidate IARC activities using a corporate governance model. Intermediary steps to unify include consolidating activities of centers and focusing on two subregional plans and coordinating their implementation through two subregional entities: one for West and central Africa, and the other for eastern and southern Africa.

In 2003, the CGIAR budget for SSA was US$173.3 million, with approximately 90% allocated to four centers in SSA: ICRAF, IITA, ILRI and WARDA. Together these four centers represent slightly over half of the CGIAR's total annual expenditure. The investment of CGIAR in SSA has remained roughly the same since the late 1990s, but it is expected to increase as a result of the Challenge Program, and the development of the two regional plans.

The Challenge Programs emphasize stronger North–South and South–South partnerships. The Challenge Program on Water for Food (CPWF) aims to increase water use in agriculture to improve livelihoods and to provide water for other users. The program is hosted by the International Water Management Institute (IWMI) and administrated by a consortium of 19 member organizations: six NARs, five

IARCs, four agricultural research institutes (ARIs), three international nongovernmental organizations (NGOs) and a river basin agency (CGIAR Science Council, 2004).

3.3 Technology Generation and Infrastructure

3.3.1 Technology generation

Many SSA countries inherited an agricultural research infrastructure established by former colonial powers. Some inherited highly specialized institutions that did not necessarily address their domestic agricultural needs; many of these institutions were unsustainable after independence when financial and human resources were withdrawn.

Despite significant expansion in the 1970s and 1980s, agricultural research in Africa remains fragmented (Anderson et al., 1994). More than half the countries in SSA employ fewer than 100 full-time researchers and governments still conduct most R&D, employing more than 75% of R&D staff in 2000. The number of agriculture-related universities, colleges and schools increased significantly and their contribution to agricultural R&D increased from 8% in 1971 to 19% in 2000. The capacity of many institutions, however, remains limited.

Nonprofit research institutions linked to producer organizations generally receive most of their funding through taxes levied on production or exports. Such is the case for research on tea in Kenya, Malawi and Tanzania, on coffee in Kenya, Tanzania and Uganda, on cotton in Zambia and on sugar in Mauritius and South Africa. Nonprofit institutions, however, still play a small role in SSA, contributing about 3% of SSA's total agricultural research capacity in 2000 (Beintema and Stads, 2004).

The distribution of technology is an integral part of any AKST system and can be accomplished via formal, informal or private distribution systems. The formal system typically involves the researcher or institution disseminating information to either a general public or specialized group through conferences, workshops and publications. This type of distribution is narrow in scope and the number of people affected is small. Knowledge is further distributed by extension services to its clients. Individuals in the community control access to information about specific topics and understanding these control mechanisms is necessary to increase the effectiveness of information dissemination.

Private sector involvement in the distribution of technology in sub-Saharan Africa is largely focused on agrochemicals and small-farm equipment and machinery. The role of the private sector is increasing as a result of trade liberalization in many SSA countries, but the environmental and safety standards of its activities are not well-regulated.

3.3.1.1 Local and traditional knowledge and innovation

Local and traditional knowledge related to agriculture ranges from production planning, cultivation, harvest practices and post-harvest handling, to storage and food processing methods. Professional specialization over the past few decades has marginalized local and traditional knowledge and the farmer-driven AKST concept. Farmers have been assumed to be relatively passive actors whose own knowledge needed to be replaced and improved. The role of women farmers in local and traditional knowledge systems has been even less valued and gone largely unexamined. However, as multistakeholder approaches to agroecosystem management started to become more common during the 1990s and as policy-making started to favor evidence-based procedures, place-based user knowledge began to regain value in science governance.

Through informal learning and adaptation, farmers, especially small-scale producers in the tropics have developed a wide range of farming practices that are compatible with their ecological niches. The biodiverse character of many farming practices facilitates environmental sustainability by provisioning diverse ecological services (Di Falco and Chavas, 2006). These practices help to ensure the conservation of the diverse genetic pool of landraces needed for modern plant breeding (Brush, 2000).

Without recognition of local and traditional knowledge and its use, technological innovations that are targeted, relevant and appropriate for the poor will be difficult to achieve (Bellon, 2006). Participatory research provides opportunities for local and traditional knowledge to interact and coevolve with formal knowledge. Formal education curricula that includes locally adapted resource management as an important focus (Gyasi et al., 2004) is an effective tool for recognizing and using traditional knowledge.

It is important to consider the cultural, ethnic and geographical origin of extension workers when preparing programs to work with farmers, including matters of dialect and terminology. Supporting networks of traditional practitioners and community exchanges can help disseminate useful and relevant local and traditional knowledge, and enable communities to participate more actively in development.

Innovative approaches are necessary to integrate and support local and traditional knowledge because its characteristics do not always harmonize with existing arrangements. For example, the normal criteria for patenting do not apply to local and traditional knowledge as this is generally preserved through oral tradition and demonstration rather than written documentation; more often than not it emerges gradually rather than in distinct increments.

The question of ownership of specific knowledge practices and of the choice of language in which to record knowledge is important. For example, West African farmers developed varieties of cowpea more resistant to bruchid beetles in storage, but the gene responsible for this resistance was later identified, isolated and patented by the UK's Agricultural Genetics Company (GRAIN, 1990). An instructive example of benefit sharing was provided by LUBILOSA, an international locust control endeavor that resulted in a mycoinsecticide, commercialized as Green Muscle™ and whose benefits are shared with national institutions (Dent and Lomer, 2001).

Evolving forms of protection of rights over local and traditional knowledge include material transfer agreements that involve providing material (resources or information) in exchange for monetary or non-monetary benefits. Examples of fair and equitable benefit sharing between users and custodians of traditional knowledge can be found in several countries. Local and traditional knowledge practices should be referenced and cited when referred to by others in books or training programs.

Regional agreements can also lead to cost-effective forms of protection for local communities. For example, the 1996 Andean Pact—adopted by Bolivia, Colombia, Ecuador, Peru and Venezuela—empowers the national authority and indigenous communities in each country, who are defined as the holders of traditional knowledge and resources, to grant prior informed consent to the application of their knowledge in exchange for equitable returns.

3.3.1.2 Biotechnology

South Africa is the only country in Africa where genetically modified (GM) crops have been approved for commercial production. It has been producing insect-resistant cotton (Bt cotton) since the 1997-1998 production season. Insect-resistant yellow maize (Bt maize) was planted in the 1998-1999 season, and in 2001, South Africa became the first country in the world to plant a transgenic staple food (Bt white maize). Approval and adoption of herbicide tolerant and "stacked gene" varieties have followed.

In South Africa, small and large scale farmers use Bt cotton in seasons when bollworm pressure is significant (Gouse et al., 2003; Thirtle et al., 2003; Shankar and Thirtle, 2005; Hofs et al., 2006). Small-scale cotton production has collapsed in KwaZulu Natal, South Africa. Competition between two cotton-ginning companies has resulted in severe defaulting on production loans and consequently no credit for small-scale producers for the 2002-2003 cotton season (Gouse et al., 2005). This story of organizational failure emphasizes the need for measures to be in place for farmers to be able to benefit from technological advances. It also stresses that in many cases instituting scientific advances is easier than establishing the social, institutional and economic conditions for progress to occur.

Crops like Bt cotton can be beneficial where farmers have limited access and means to acquire insecticides and where cotton gins can supply credit using the anticipated harvest as collateral. Gins in collaboration with seed companies can also control the flow of seeds. However, on a continent where the use of hybrid maize seed is more the exception than the rule, widespread adoption of insect-resistant or herbicide-tolerant maize is doubtful. In SSA, where factors like HIV/AIDS and urbanization are putting pressure on the aging rural workforce, a labor-saving technology like herbicide-tolerant maize may help (Gouse et al., 2006). Whether farmers will be able to afford this technology and the herbicide is questionable and financial institutions are historically resistant to funding inputs for dryland subsistence farming.

South Africa has a vibrant seed industry that includes GM products, a functional biosafety regulatory framework, and over 500 transgenic field trials conducted to date. Kenya has a thriving horticultural industry based on vegetables, fruits and ornamentals (Minot and Ngigi, 2004). In recent years Kenya has initiated field trials in Bt maize, Bt cotton, sweet potato and virus-resistant cassava. While the sweet potato trials might not have yielded the expected results due to a mismatch in the viral coat protein gene used in the transgenic plants and the prevailing local virus strains, it was a landmark case insofar as getting the country to begin assembling the requisite structures for a functional biosafety framework. Kenya has created an enabling environment that has attracted other resources. It now has a biosafety level 2 greenhouse and a genetic transformation laboratory at Kenyatta University. Also in Kenya are Biosciences East and Central Africa, and the African Agricultural Technology Foundation for brokering royalty-free proprietary technology for SSA. Kenya is host to a significant number of international research institutions, donors and development partners. The seed industry is receiving substantial support with the development of new seed delivery programs such as the Program for African Seed Systems (PASS) of the Alliance for a Green Revolution for Africa (AGRA).

Uganda established a biotechnology laboratory in Kampala in 2003 for tissue culture of such crops as the East African highland banana and coffee. In 2007 Uganda began trials for a transgenic dessert banana developed in Belgium and purported to resist bacterial wilt and black Sigatoka fungal disease (Dauwers, 2007) and approved Bt cotton field trials (UNCST, 2007). The Program for Biosafety Systems is establishing country offices in both Kenya and Uganda to handle biosafety requirements in response to these developments.

A big issue facing SSA is the lack of qualified personnel to use the many available biotechnologies in tissue culture, molecular markers, diagnostics, genetic engineering, nanotechnology and synthetic biology. Another issue is the lack of strong intellectual property rights. South Africa is the exception, filing annually for more patents than all those filed by the African Regional Intellectual Property Organization (ARIPO). South Africa would like to attract not only ARIPO's Anglophone member countries, but also Francophone countries to form a broader legal platform (Crouch et al., 2003).

Conflict and instability inhibit advances in sub-Saharan Africa's AKST system generally and its biotechnology capacity in particular. Zimbabwe provides one example. Once acknowledged for its superior capacity in biotechnology, the economic climate hinders the country's active participation in key regional initiatives that are currently attracting donors and the country suffers from substantial loss of human resources.

3.3.2 Infrastructure

Infrastructure plays a critical role in science, technology and innovation efforts in developing countries and is one of the most important factors in attracting foreign direct investment. Paradoxically, the poor state of Africa's infrastructure is partly because of a lack of investment.

Rapid technological change and increasing investment in transportation, communications and information technology have facilitated and partly driven the geographical diffusion of production processes across countries. Technological change has led to growing integration of world capital markets, increasing the international flows of short- and long-term private capital. However, these flows have largely left the poorest countries untouched because of their low level of technological development (IFPRI, 2001).

3.3.2.1 Transportation

Transportation infrastructure (roads, railways, harbors, airports) has a profound effect on the ability of agricultural producers to exploit economies of scale and to promote efficiency through specialization. This is particularly so where roads and railways reduce transportation costs and open new markets and where harbors and airports create opportunities for exports and contribute to lowering the costs of imported agricultural inputs (Estache et al., 2005). Subsistence agriculture is least affected because it uses few external inputs and the produce is consumed locally. Although literature on the link between transport and poverty is fairly substantial, there is little on the link between transportation infrastructure and AKST. Effective transportation infrastructure is generally associated with greater agricultural output, higher incomes, better indicators of access to health services and greater wage income opportunities. The effect of road infrastructure on poverty alleviation is positive and significant, partly because of the effect on market access and on agricultural and rural development (Bhattarai and Narayanamoorthy, 2003).

Transportation infrastructure in most SSA countries is generally underdeveloped and in some places underused. This is partly attributed to the fact that transportation infrastructure, although important, is expensive to build and maintain, difficult to manage and easy to abuse, mainly by overloading vehicles (Farrington and Gill, 2002). SSA has an estimated 1.8 million km of roads, of which only 16% are paved. Rail, marine and air freight are low, making up less than 2%, 11% and 1%, respectively, of the world's totals. Marine transport is rare since 90% of Africa's land and 80% of its populated area lies more than 100 km from the coast, lake or a navigable river. In some cases, where transportation infrastructure is built for broad commercial objectives, builders have failed to take into account the special needs of specific subsectors such as fisheries, livestock and forestry. While many airports have sufficient runway capacity to handle large cargo planes, limited trade volumes and inadequate cold storage facilities hinder the export of high-value perishables (NEPAD, 2002).

Inadequate and ineffective transportation infrastructure constrains investment and market integration in rural areas, mainly because of the high cost of transportation. Landlocked countries pay high prices for imports and get low prices for their exports. For example, importers in the Central African Republic and Chad pay cost, insurance and freight (CIF) prices that are 1.3 to 1.8 times the cost of the products when they leave the exporting countries, while their coffee is 2.8 times the production cost when it arrives in Europe. The main economic reason for inadequate fertilizer input in SSA is poor transportation infrastructure (Sanchez and Swaminathan, 2005). In Burkina Faso, Uganda, and Zambia walking is the principal means of transportation for 87% of rural residents (Torero and Chowdhury, 2004). This affects labor productivity and indirectly constrains agricultural development.

Some agricultural areas are well connected to markets, particularly the major food and cash crop-producing areas. In Kenya, export horticultural produce is grown in areas with good road infrastructure and the government gives priority to improving roads in the main food and cash crop-producing areas (Kenya Ministry of Agriculture, 2004). Location and climate greatly affect income levels and income growth, causing differences in transportation costs, health and agricultural productivity (Gallup et al., 1998). There is linear correlation between GDP and road infrastructure (Estache et al., 2005). In relatively wealthy SSA countries such as South Africa, Namibia and Botswana, most high-potential agricultural areas are well linked to the market, whereas in poorer countries like Burkina Faso, Eritrea and Chad, most of the areas with high agricultural potential are poorly linked. In general, many parts of poorer SSA countries with agricultural potential are not exploited because of the absence or poor state of transportation infrastructure. In the two leading milk-producing districts in Kenya, milk waste is 30%, mainly because of the difficulties in getting milk to the market or processing plant in time, particularly during rainy seasons (Neondo, 2002).

Where transportation infrastructure is effective, an increase in agricultural yields of one-third might reduce the number of poor by 25% or more (Irz et al., 2001; Farrington and Gill, 2002; Mellor and Ranade, 2002). Consensus is growing that providing adequate infrastructure for transportation is an important step toward alleviating poverty and providing equitable opportunities for rural citizens by linking small-scale producers to markets and reducing the market risk and transaction costs they face.

3.3.2.2 Water and energy

Infrastructure for agricultural water management is required to facilitate agricultural expansion and intensification in semiarid and arid areas (irrigation infrastructure), to remove excess water (drainage infrastructure), to support intensification of rainfed agriculture (water-harvesting infrastructure) and to encourage recycling and reuse. Water storage is required to reduce the mismatch between water supply and demand and to protect downstream agriculture in floodplains from flood damage. To avert the emerging water crisis in many parts of SSA, additional water storage needs range from 751 m^3 $person^{-1}$ in Lesotho to 152 m^3 $person^{-1}$ in Burkina Faso (Grey, 2004).

Small reservoirs reduce climate risk, facilitate adoption of higher-yielding crop varieties, increase appropriate fertilizer use, and make possible better crop, soil and water management practices (Faulkner, 2006). These improvements lead to greater resource efficiency, a 40-160% increase in maize yield and a 30-85% increase in profitability. Irrigation potential is largely unexploited, partly because of inadequate water storage and the high cost of irrigation infrastructure (FAO, 1995, 2005). Small reservoirs in northern Ghana and southern Burkina Faso have played a critical role in improving agricultural output and enhancing food security (Andreini et al., 2000). Ongoing research that is part of the CGIAR Challenge Program is intended to optimize benefits in the community by developing small reservoirs and reducing the negative effects arising through overuse of water in the upper reaches of rivers (Andreini et al., 2005).

Development of high-yielding varieties and the need to increase agricultural outputs in semiarid and arid areas have been the major drivers of irrigation development. Irrigation in turn has led to increased access to and adaptation, adoption and effectiveness of AKST. The full range of irrigation development options should be critically examined so that the best choices are made to suit the type of farmers, farming system and agroclimatic zones.

Sixty percent of the primary energy supply in SSA is from biomass, and close to 90% of the population uses biomass for cooking and heating (Holmberg, 2007). Even oil-rich SSA countries continue to rely on biomass energy to meet the bulk of their household energy requirements. In Nigeria it is estimated that about 91% of household energy needs are met by biomass. The problems associated with a reliance on biomass include inefficient heat conversion; respiratory disease; minimal poverty alleviation; and land degradation (Holmberg, 2007).

Few African villages have electricity (Torero and Chowdhury, 2004). Most rural areas have not been able to develop agroindustries or to tap groundwater resources needed to support intensified and diversified agriculture. There is a general perception that rural electrification projects are good for the poor, but relatively little research links rural electrification with agricultural growth and poverty reduction.

3.3.2.3 Storage and processing

Providing agricultural storage infrastructure helps alleviate poverty and improve food security with increased benefits for women and children.The presence of storage facilities has implications for the profitability and marketability of farm produce. On-farm storage at individual farm homes is the norm in SSA. In Uganda, for example, approximately 54% of farmers use local granaries with capacities of 0.2-0.5 tonne and another 42% store in their residential houses (Uganda Investment, 2005). Generally, product loss is high (5-60%) because storage structures are defective (FAO, 1994; Haile et al., 2003). There is a need to develop improved and more efficient storage structures for farmers.

Few large-scale commercial storage facilities exist in most SSA countries (Fay and Yepes, 2003). In Uganda, silos, warehouses and stores with capacities ranging from 2,500 to 18,000 tonnes are the main form of bulk storage (Uganda Investment, 2005). Private sector involvement in storage is limited because volume is low and the logistics associated with collecting small amounts of produce from farmers scattered over a large area are problematic.

Inadequate processing and storage infrastructure close to the main producing areas inhibits value addition. In combination with other factors, the lack of storage infrastructure contributes to low farm-gate prices for outputs and is a disincentive for resource-poor farmers to shift from subsistence to market-oriented agriculture. There is relatively little processing of agricultural produce in SSA. Small-scale cottage industries exist that specialize in processing, but they provide only first-level processing services. The major problem they face is availability of raw materials to keep the factories running to ensure their viability and profitability (Platteau, 1996; OECD, 2006).

3.3.2.4 Information and communication technology

ICT infrastructure. The development and use of ICT has tremendous potential for increasing access to information, but realization of this potential has been uneven. Newspapers and radio have had the greatest market penetration but cell phone coverage is growing rapidly. Landline telephony, Internet access, television (particularly pay TV) and PC access are weak in many places and nonexistent in many others. Some SSA countries are constrained in taking advantage of ICTs because of restrictive policies, barriers to investment, lack of funds for extending access to their populations and socioeconomic barriers to Internet use and ICT coverage.

Cell phone technology. The weakness of landline telephony and the dysfunctional nature of national postal systems prompted the adoption of email—in the limited areas where it was available—much earlier in sub-Saharan African countries than in some industrialized countries, where sufficient telephone and postal infrastructures initially blunted incentives to adopt e-mail (Levey and Young, 2002). More recently, mobile phone coverage and adoption has followed a similar pattern, with comparatively high rates of uptake. From 2000 to 2003, the number of mobile phone subscribers in sub-Saharan Africa increased from 15.7 million to 51 million (ITU, 2004); by 2004, the number had risen to 82 million (Itano, 2005).

Although there are currently more subscribers to landlines than cell phones, this will reverse as sub-Saharan African countries "leapfrog" over the development of their ailing landline telephone infrastructure and rely more heavily on cell phone coverage to meet their needs. As cell phone markets innovate to exploit what is now understood to be the enormous market potential of cellular technology, prices for handsets have come down sharply and pricing options have multiplied to cater to the various segments of the market. The lower prices have put cell phone service within the reach of some of the poorer strata of society, though not the very poor. A case in point is Uganda, where competition emerging in the late 1990s disrupted a local monopoly and brought about positive changes in cell phone reach and coverage, as well as in local prices (Uganda Ministry of Works, Housing and Communications, 2003). Competition is clearly central to the extension and adoption of many ICTs (Figure 3-1) (ITU, 2004).

The implications of increased access to agricultural knowledge are suggested in reports of farmers using cell phone technology to send and receive market informa-

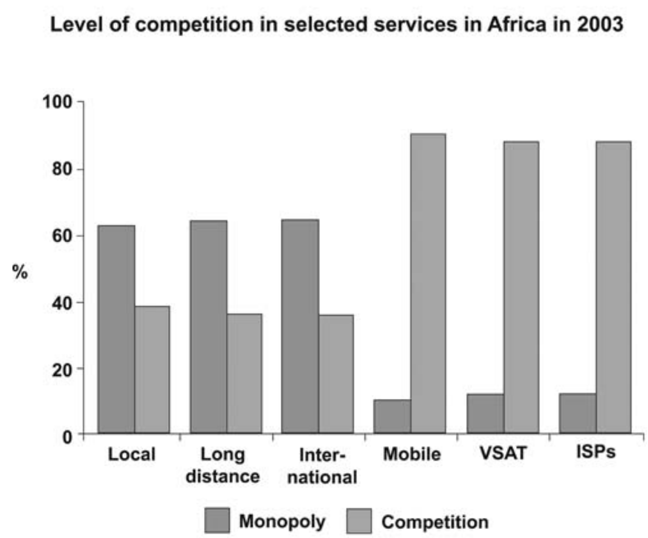


Figure 3-1. *Level of competition in some ICT services in Africa in 2003. Source: ITU, 2004.*

tion, usually via short message service (SMS) text messages. There are also some reports of seed, fertilizer and other input companies using text messages to disseminate simple information on product use. Thus far, there has been little comprehensive analysis of the effect of ICTs on the dissemination of agricultural knowledge and the production of agricultural goods. In a study commissioned by Vodafone, anecdotal evidence was confirmed of fishers in Tanzania using SMS text messaging to obtain information about market prices offered at the landings. Based on the information they received, fishers landed their boats where they would receive the best price for their catch (Vodafone, 2005). The same study found maize farmers in the Democratic Republic of Congo reduced theft by equipping guards with cell phones (Vodafone, 2005).

Many people who are not cell phone subscribers have access to them through friends and neighbors. In Tanzania, for example, a study conducted by the UK mobile phone company Vodafone found that 97% of people surveyed had access to a mobile phone, compared with just 28% who had access to a landline phone (BBC, 2005). The same study found that cell phone technology plays a key role in linking black-owned businesses in South Africa to their customers. Businesses in South Africa and Egypt reported higher earnings directly related to access to cell phone technology. Research conducted through a partnership among Vodafone, the Consultative Group to Assist the Poor (CGAP) and World Resources Institute (WRI) found that cell phone banking, or "m-banking," piloted successfully in Kenya, makes banking more affordable for poor people in South Africa and has the potential to extend microfinance services to larger segments of non-banking poor populations. In addition, mobile banking through airtime transfers has increased women's freedom and created commercial opportunities for micro-entrepreneurs reselling airtime (Vodafone, 2006).

Internet. Internet connectivity is central to the ability of African agricultural researchers to exchange, consume, adapt and apply agricultural knowledge generated with and by their regional and global colleagues, and contributes to regional and global agricultural knowledge in Africa. Some initiatives seek to extend Internet access to African agricultural researchers (USAID, 2003), while others create opportunities for collaboration between African farmers and related sectors such as those working with natural resources management (www.frameweb.org). Lack of access in some locales severely disadvantages African agricultural researchers, students and policy makers.

Constraints to Internet access and affordability include those related to cable infrastructure, connections within SSA countries and between SSA and the rest of the world. Underwater cable connections have been addressed differently in different parts of the continent, particularly regarding questions between closed vs. open access. Future comparisons of the two as their impacts unfold are needed.

The SAT3, or SAT3/WASC/SAFE Consortium, an undersea fiber cable running from Portugal to South Africa and across the Indian Ocean to Asia, has component segments measuring a total of 28,800 kilometers (Fibre for Africa, 2007a). The system is divided into two subsystems, SAT3/WASC in the Atlantic Ocean and SAFE in the Indian Ocean (Figure 3-2). The consortium's 36 members (12 of whom are African countries) have invested US$600 million to build and operate for the next 25 years. SAT3 has been controversial because its business model is such that members use it as a first-line business, making their profits from charging for communication access rather than using it to open up communication to facilitate the development and growth of second-line businesses. Moreover, there is no competing system. Thus, in consortium member countries, the incumbent telecoms operators have been granted a national monopoly and control the fees charged for international bandwidth. Consequently, prices remain high and there is little incentive to lower them.

The situation in East Africa is different, but also controversial because of donor involvement and debates over the extent to which the initiative will remain open access. The cable infrastructure in East Africa, the East Africa Submarine Cable System (EASSy) plans to connect eight eastern and southern African coastal countries (Sudan, Djibouti, Somalia, Kenya, Tanzania, Mozambique, South Africa and Madagascar) to other global undersea cable systems, including SAFE in South Africa and SEA-ME-WE 4, and potentially others, in the North. Eleven other land-locked countries (Ethiopia, Lesotho, Uganda, Swaziland, Rwanda, Malawi, Burundi, Zimbabwe, Zambia, Botswana and the Democratic Republic of Congo) will be connected to the system. The project cost is estimated to be US$200 million (Fibre for Africa, 2007b).

Meanwhile, NEPAD is working in coalition with NGOs, Internet service providers and regulators to maintain open access, which is defined as access for all operators having equal capacity, pricing and bandwidth. This coalition is seeking to block the development of monopolistic control of bandwidth as in the SAT3 project in West Africa, to prevent high prices. EASSy investors, comprised of 31 telecommunication companies, have proposed a model similar to SAT3 but that does not include equal access to capacity and prices (East African Business Week, 2007).

Once the undersea cables are in place and they link SSA to the rest of the world, the next step will be to establish Internet exchange points (IXPs) that connect in-country Internet service providers (ISPs) to the undersea cables. IXPs will allow Internet traffic to move within the region without transiting through Europe or North America. At issue is whether the new technologies will be accompanied by equitably designed licensing practices and attract both local and foreign investment. Progress on IXPs is being made, with national ones operational in the Democratic Republic of Congo, Egypt, Kenya, Mozambique, Nigeria, South Africa, Uganda, Tanzania and Zimbabwe (Fibre for Africa, 2007c).

Other issues. Once the basic infrastructure is in place, other factors affecting ICT access and use for development will need to be addressed, including availability, censorship, rights and freedom of expression, content and language, intellectual property, Internet governance, national ICT strategies and policies, and security and privacy (Hamilton et al., 2004).

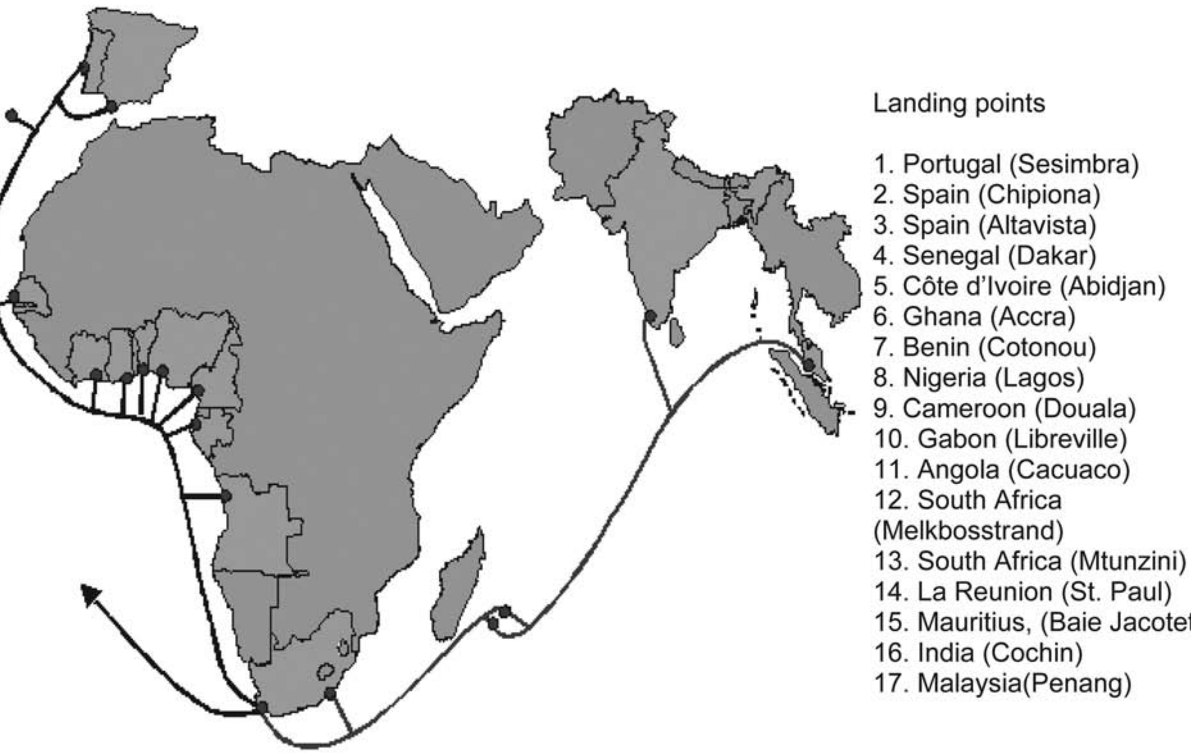


Figure 3-2. *SAT3 fiber cable routing with landing points. Source: Fibre for Africa, 2007c.*

3.4 Natural Resource Management and the Environment

Technologies that address a single component of agriculture such as biophysical constraints but neglect, for example, the socioeconomic context have not been widely adopted (Omamo and Lynam, 2003; IAC, 2004). Issues such as property rights and collective action are important in determining who benefits from increases in productivity (Meinzen-Dick et al., 2002). Resource scarcity and unequal distribution of access to these resources can lead to violent conflict, as has been witnessed in both Zimbabwe and Cote d'Ivoire. AKST is increasingly influenced by interactions between biophysical and socioeconomic processes (Norse and Tschirley, 2000).

Many SSA countries have formulated policies, enacted laws and established agencies to conserve biological diversity, often under the guidance of local chapters of the World Conservation Union (IUCN—formerly International Union for the Conservation of Nature). These policy regimes address different components and issues of biological diversity and its management. While some focus on ecosystem management as a whole, others are devoted to regulating and conserving specific components.

3.4.1 Land and water management

A number of strategies have been put forward to integrate the many aspects of agriculture in order to address sustainable livelihoods (Scoones, 1998). Among them are sustainable agriculture, integrated water and watershed management (FAO, 1997; Lal, 1999), agroforestry (Franzel et al., 2001; Beer et al., 2005), integrated soil fertility and nutrient management (Bationo et al., 1998; Vanlauwe and Giller, 2006) and local knowledge. Newer approaches such as ecoagriculture (McNeely and Scherr, 2003) build on the objective of conserving biodiversity while increasing productivity and livelihood security.

Integrated natural resource management is seen as a useful approach or framework for integrating the multiple aspects of agriculture to achieve sustainability and development goals (Izac and Sanchez, 1998; Palm et al., 2005). It combines technological, social, economic and institutional innovations and methods with the goal to improve support services for research and development, as well as development strategies and policies (Figure 3-3). It aims to build on local knowledge by conducting participatory research to augment people's capacity to manage their local natural resources, enhancing social, physical, human, natural and financial gains (Harwood and Kassam, 2003; Thomas, 2003) Building agroecosystem resilience through nutrient cycling, carbon sequestration, water management and conservation of biodiversity is a crucial part of an integrated framework.

Assessments of the effectiveness of integrated natural resource management are mixed. One constraint is the lack of well-described pathways that can trace the effect of research outputs on development (Gottret and White, 2001). Hierarchical approaches contend with important questions such as who wins and who loses. Research in eastern Africa on integrated watershed management has shown that "participation" in diagnosing problems and implementing programs must move beyond community-level forums to so-

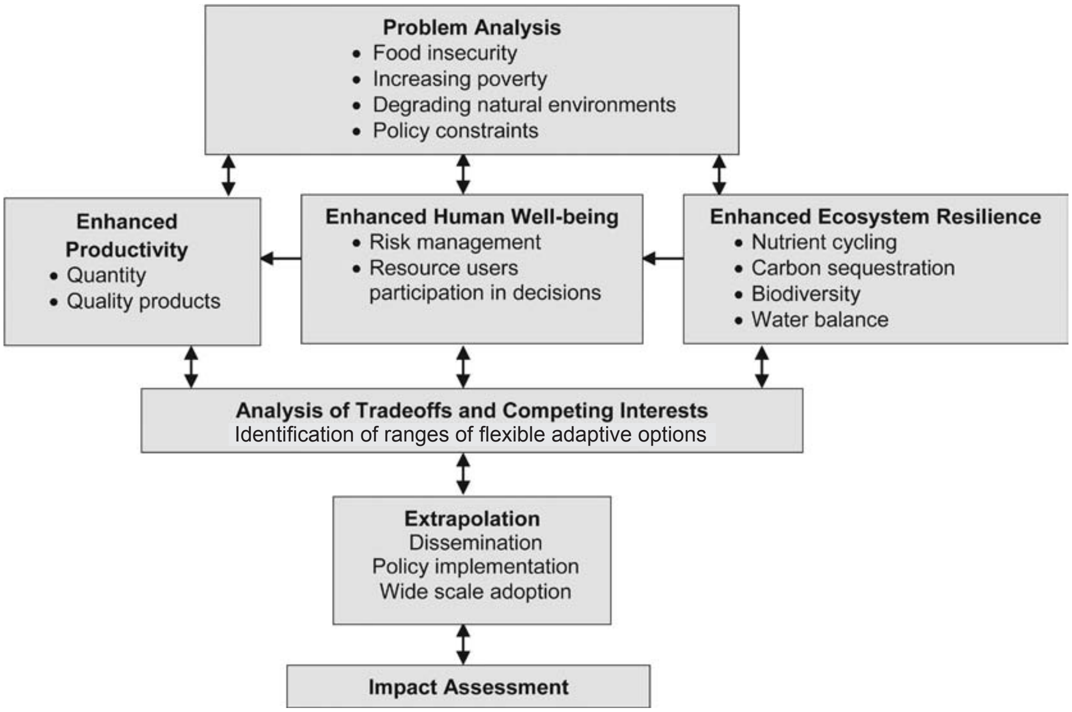


Figure 3-3. *Integrated natural resource management (INRM) approach. Source: Izac and Sanchez, 1998.*

cially disaggregated processes and explicit management of tradeoffs among diverse groups. Moreover, a mere set of activities and interventions will not revitalize a system unless its various components are explicitly analyzed for potential tradeoffs and synergies (German et al., 2007).

3.4.1.1 Land and soil degradation

In Africa, the total area of degraded lands is estimated to be 128 million ha. Degradation occurs mostly in the drylands and tropical forest margins where soils have lost their ability to provide ecosystem services (such as nutrient cycling, water filtration, waste absorption and the breakdown of vegetative cover and soil formation) and have become a source of crop yield decline (UNEP, 2002). In SSA, 65% of agricultural cropland and 31% of permanent pasture are estimated to be degraded with 19% of the land seriously degraded (Scherr, 1999).

Soil nutrients vary greatly across locales and countries. Even in resource-limited small-scale agriculture, not all fields are continuously mined; some fields have positive nutrient balances, usually through use of nutrients concentrated from other parts of the farm (Vanlauwe and Giller, 2006). Yet depletion of soil fertility in SSA is a major cause of low production (Kumwenda et al., 1997; NEPAD, 2002; Ajayi et al., 2006; Henao and Baanante, 2006; Okalebo et al., 2006). The factors contributing to low use include limited access to credit, poor infrastructure in rural areas, weak purchasing power among poor farmers, limited access to fertilizer information, few trained fertilizer stockers, inputs not in affordable sizes, low and irregular supplies and lack of appropriate fertilizers for local conditions (Okalebo et al., 2006).

There are large variations in fertilizer use among countries (IAC, 2004). Increased fertilizer application is seen by most scientists as essential, yet availability and costs constrain farmers in SSA and soil moisture stress limits the uptake of nutrients. There is a need to conserve both water and soil organic matter. Phosphate rocks of various origins and agronomic effectiveness are found widely in Africa (Okalebo et al., 2006).

Research has focused on options for land and soil management that would alleviate biophysical, land-related constraints. These include soil erosion, low levels of major nutrients (organic N in soil organic matter, P and K), loss of vegetative cover, extreme climatic events (see Chapters 1 and 2), and socioeconomic factors such as access to markets and opportunity to develop them and access to land and labor.

Substantial progress has been made in developing new tools and technologies and applying them to participatory agricultural approaches. These include the integration of geographic information systems and remote sensing, agroecological and farming systems analysis, monitoring and evaluation of ecosystem services, rapid spectroscopy techniques of soil analysis, and molecular tools to study soil biodiversity (Shepherd and Place, 2006). Research has resulted in major innovations in crop–livestock–tree systems, as well as practical options for soil fertility improvement. Although constraints still exist, changes in land use patterns and increased productivity have been noted in several key farming systems (IAC, 2004).

3.4.1.2 Climate change

Climate change, which affects the resilience of farming systems, plant and livestock growth and yields will be increasingly important in SSA (IPCC, 2007). A recent analysis of long-term trends (1900 to 2005) indicates rising temperatures in Africa as a whole, and drying or decreased precipitation in the Sahel and southern Africa (IPCC, 2007). Climate change will particularly affect small islands such as those of the western Indian Ocean, Seychelles, Comoros and Mauritius, and coastal areas.

Many in Africa already experience climate extremes and are vulnerable to the effects of flooding, soil erosion, drought and crop failure (Thomas and Twyman, 2005; IPCC, 2007). The negative effect of these extremes is particularly severe for poor people, who have the least adaptive capacity and are the most vulnerable to climate change (Kandji et al., 2006). Resilience is inhibited by fragile ecosystems, weak institutions, poverty and ineffective governance. Deforestation and changes in land use are other factors that diminish the resilience of agricultural systems, particularly with regard to the availability of ground and surface water (MA, 2005; CA, 2007).

The need to build Africa's adaptive capacity in regard to climate change is considered a priority by African governments and donor agencies. Methods for coping with short-term climate variation—a proxy for dealing with longer-term climate change—are an important factor driving AKST (Thornton et al., 2006). Rainfall variability is the fundamental factor defining production uncertainty, and while farmers have learned to cope with current climate variability, they are risk averse and are reluctant to make investments when the outcome seems uncertain from year to year (Cooper et al., 2006).

There is a need to establish strong national and regional research centers, particularly for global change research and to identify past initiatives that hold potential but were insufficiently funded. Increasing the number of scientists researching climate change in SSA is a prerequisite for medium- and long-term empowerment in the research arena. This can be achieved by granting doctoral fellowships for young scientists and small grants to assist them in their research. These measures could help limit competition among organizations and avoid redundancy.

Cooperation among climate change initiatives in SSA will be critical in order to disseminate results and avoid duplication of work. Some recent initiatives include the African Monsoon Multidisciplinary Analysis program, which builds scientific capacity through training of trainers programs and supervision of junior scientists, and the Climate Change Adaptation in Africa Research and Capacity Development Program, a capacity building program sponsored by the UK Department for International Development and the Canadian International Development Research Centre (DFID/IDRC).

3.4.1.3 Agroforestry systems

Researchers have been accumulating knowledge for the past 20 years with respect to technologies developed to deal with low soil fertility and land degradation. Their research involves various types of farm experiments such as intercropping legumes and cereals. Some technologies such as hedgerow cropping were not adopted because they required additional labor (Franzel and Scherr, 2002).

More recently, experiments with sequential and improved fallows, which intercrop trees such as *Sesbania sesban* and *Tephrosia vogelii* with crops such as maize, have been increasingly successful (Ajayi et al., 2003; Place et al., 2004). For example, improved fallows of 8-21 months, or one to three seasons, can increase yields two- to fourfold (Place et al., 2004). In eastern Zambia, e.g., 77,500 farmers were known to have adopted tree fallow systems in 2003 (Ajayi et al., 2006). Studies conducted in southern Malawi, eastern Zambia, western Kenya and the humid zones of Mali also show that the highest yields were obtained with repeated application of the recommended rates of synthetic fertilizer.

Agroforestry techniques that have been adopted with some success include mixed intercropping with *Gliricidia*, natural vegetative strips, biomass transfers, shaded perennial crop systems and other innovations to improve soil and land management. Yields can increase by two to three times those of current farming practices (Franzel and Scherr, 2002). In western Kenya, for example, managed short-duration fallows have the potential to replace longer fallows in regions where population density no longer permits slow natural fallow successions. The fallows improve crop performance and restore soil fertility and organic matter content in the long term. They use trees such as *Tithonia diversifolia* and *Crotalaria grahaminia* in soils where phosphorus is a limiting factor for productivity (Smestad et al., 2002). A gliricidia–maize (*Gliricidia sepium–Zea mays*) intercropping system has shown that it is a suitable option for soil fertility improvement and yield increases in highly populated areas of sub-Saharan Africa, where landholdings are small and inorganic fertilizer use is low. In these trials, P and K fertilizers were applied and the gliricidia provided N among other benefits (Makumba et al., 2006).

Natural fallows, if done in short rotation, provide poor results, except in some parts of the humid tropics (Hauser et al., 2006). Experiments using legume tree fallows invariably show positive and significant yield increases, except where soils have severely limited P or K or are in arid areas (Mafongoya et al., 2006ab). Here their performance varies, but there are similar results with synthetic fertilizer as well. It remains unclear whether the technology has high potential for adoption or whether it can be repeated without adding other nutrients. It has been consistently found that integrating a tree fallow with small doses of fertilizer is the best option technically and economically. Fallows with herbaceous legumes do not generate as much biomass, and in the case of grain legumes, much of the nutrients are harvested (Mafongoya et al., 2006a).

In the Sahel parklands, indigenous nitrogen-fixing trees, like *Parkia biglobosa*, *Vitellaria paradoxa* and *Faidherbia albida,* have been planted for rehabilitating degraded lands that farmers protect and manage. These areas serve as sources of wood, food, fodder and medicine, and they provide soil fertility for the ecosystem (Teklehaimanot, 2004). Because of pressure on the land, the number of these trees is declining. Vegetative propagation methods, which allow multiplication of superior trees, and on-farm domestication are helping maintain their important role in rural livelihoods.

Fodder shrubs to feed dairy cows have been adopted by about 200,000 farmers in Kenya, Rwanda, Uganda and northern Tanzania over the last decade. Fodder shrubs are attractive to farmers as protein supplements for dairy cows because they require little or no cash expenditure, nor do they occupy fertile land, as they are grown along boundaries, pathways, and across contours to curb soil erosion. Like many agroforestry and natural resource management practices, the adoption of fodder shrubs requires knowledge that is not always available to the farmer, such as raising seedlings, pruning trees and feeding leaves to livestock. Five factors contribute to the adoption of fodder shrubs: large NGOs promoting them, farmer-to-farmer dissemination, private seed vendors, trained extension agents and the integration of fodder shrubs into bigger projects. AKST is driven by the need to understand how these knowledge-intensive practices can be more efficient and effective (Franzel and Wambugu, 2007).

Technologies for replenishing soil fertility often increase labor requirements and require careful management. Some options are to withdraw land from agricultural production for various periods of time, which could prove costly to the farmer. The returns on investments vary and are related to market opportunities and farm prices for crops (Kante, 2001).

3.4.1.4 Tree domestication

Herbaceous and woody species of trees are now being domesticated to meet the needs of local people for traditional foods, medicines and other day-to-day products (see Global Chapter 3). Agroforestry tree domestication involves developing useful tree products for farmers. It leads to diversification of small-scale farms in the humid, subhumid and drylands of SSA. It also provides farmers the opportunity to generate a cash income. It can only be successful, however, if developed with appropriate market opportunities.

Over the past 50 years, rural populations in Africa have increasingly planted trees for the tree products and services farms require, as opposed to relying on natural forests. This trend underscores the fact that forests in Africa are the most depleted of any tropical region, with approximately one-third of the original forest area remaining (Sayer et al., 1992). The deforestation rate is 1.7% annually. Africa is the least forested tropical continent with only 21.4% forest cover as a percent of land area in 2004 (FAO, 2007), in comparison to South America, which has 47.7% of its land in forests. On-farm tree planting varies from country to country in almost direct negative correlation to forest cover percentage and per capita forest cover. The range for forest cover percentage and per capita forest cover varies from 1% tree cover in Niger to 85% in Gabon; per capita forest cover varies from 0.1 ha in Ethiopia to 18.2 ha in Gabon. Local populations have always been familiar with the services and functions provided by trees including soil improvement, biodiversity habitat, stored energy, reduced soil erosion, shade, windbreaks and boundary markers.

A landmark meeting of the International Union of Forest Research Organizations in 1992 revealed how far Africa lagged behind in the area of tree domestication relative to Asia and the Pacific (Leakey and Newton, 1994). This information triggered a large increase in the amount of tree research being carried out in Africa (see Leakey et al., 2005). Participatory tree domestication, an approach that involves farmers, market traders and consumers in activities such as species prioritization, trait selection, germplasm collection and strain development (Simons and Leakey, 2004), has been well received. These initiatives are now beginning to show positive impact in terms of increased tree planting (Franzel and Scherr, 2002) and increased product quality (Tchoundjeu et al., 2006).

Fruit trees are important for nutrition in SSA, where nutrition levels are the lowest in the world, and have been the target of domestication efforts. In Zimbabwe, trees such as *Diospyros mespiliformis*, *Azanza garkeana* and *Strychnos cocculoides* are important for household nutrition, and plantings have remained constant in proportion to climax woodland and cleared agricultural land. These trees bear fruit seasonally. In southern Africa, customary conservation practices range from seasonal restrictions on gathering medicinal plants to the widespread social conventions that prevent the felling of fruit-bearing trees such as wild medlar (*Vangueria infausta)* and magic gwarra (*Euclea divinorum)*. These species are important in the maintenance of biodiversity on communal lands.

Post–World War II global concerns for timber supply drove the establishment of industrial plantations for sawnwood and paper in Africa and elsewhere. Pan-tropically suitable timber species, such as *Pinus* spp., *Eucalyptus* spp., and *Acacia* spp. were preferred (Barnes and Simons, 1994). These plantations were established predominantly on remote land or land of low suitability for agriculture, and they were primarily geared for export. In SSA, the most significant tree product required was fuelwood.

Recognizing an impending shortage of fuelwood and animal fodder, development-oriented forestry programs emerged in the 1970s and 1980s. These programs used multipurpose trees and relied heavily on exotic species, some of which have since become invasive (e.g., *Acacia, Prosopis*). Most planting efforts focused on Australian acacias, Central American dry-zone hardwoods, casuarinas, sennas and neem (*Azadirachta*).

Two trends have been noted in SSA: the number of trees in forests is declining and the number of people on farms is increasing (Tiffen et al., 1994; Place, 1995; Place et al., 2001; Kindt et al., 2004). Chapter 3 of the Global Assessment describes the relationship between farmers and depleting forests: after the forests are removed, tree populations increase as farmers integrate trees into their farming systems (Michon and de Foresta, 1999; Place and Otsuka, 2000; Schreckenberg et al., 2002; Kindt et al., 2004). This counterintuitive relationship, observed in West Africa (Holmgren et al., 1994), East Africa (Kindt et al., 2004; Boffa et al., 2005) and the Sahel (Polgreen, 2007), seems due, in part, to the availability of labor, domestic demand for traditional forest products and for marketable cash crops, and to risk aversion (Shepherd and Brown, 1998). In Cameroon, for example, tree density is inversely related to farm area, ranging from 0.7-6.0 ha (Degrande et al., 2006) and similarly, a given area of land has a greater abundance and diversity of trees when it is composed of small farms (Kindt et al., 2004). Recent studies show that there may be a rich diversity of trees in some locations, and a dirth in others (Kindt et al., 2004; Lengkeek et al., 2005). Some of the lower rates of diversity have been attributed to bottlenecks during the tree nursery stage (Lengkeek et al., 2005).

3.4.1.5 Improved and adaptive crop cultivars

The development of a wide range of improved cultivars has been instrumental in the effective use of land in many parts of the continent. Uganda farmers have developed 60 different cultivars that have adapted to the production systems in the central African highlands. AKST has led to similar improvements in cotton production in the Sahel, maize in eastern and southern Africa, and wheat in southern Africa. Work by IARCs and NARIs has played an important role in mitigating the spread of crop diseases and pests in large parts of the continent, making it possible for millions of small-scale farms to use arable land efficiently.

In the arid and semiarid lands of eastern and southern Africa, AKST has been instrumental in helping farmers select and manage germplasm for staples. Drought-tolerant varieties have made it possible for vulnerable farmers to better use land in areas that are predisposed to extreme rainfall variability.

3.4.2 Water management

3.4.2.1 Linking water, AKST and development and sustainability goals

Agricultural production is constrained when water quantity, quality and timing do not match the water requirements of crops, trees, livestock and fish. The amount of water required for agriculture is extremely high compared with other uses. Massive water use in agriculture has negatively affected other water users and the environment. Lake Chad declined from 25,000 km^2 in the 1960s to 1,350 km^2 in 2001, mainly because of the fourfold increase in water withdrawal for irrigation between 1983 and 1994 (UNEP, 2002). Dry season flows in most SSA rivers are declining because of upstream irrigation and reservoirs (UNEP, 2002; Gichuki, 2004). AKST has contributed to unsustainable water use through: the adoption of higher yield crops that are water demanding, such as rice; limited attention to water-saving technology; limited adoption of yield-enhancing technology in rainfed agriculture; and inadequate development of technologies to enhance the use of marginal water sources.

Water resources in SSA are poorly distributed. In 1999, water was abundant in 53% of Africa's land area, which was home to 60% of the population, some 458 million. By 2025, water-scarce areas are projected to increase from 47% to 64%; these areas would have 56% of the population but only 12% of the continent's renewable water resources (Ashton, 2002).

Over the last 50 years, the water crisis in SSA has intensified. This is likely to continue, driven partly by:

- Increasing population and per capita consumption.
- Climate change scenarios in southern Africa suggest that seasonal and yearly variability in rainfall and runoff will increase with some regions getting drier and others more wet (IPCC, 2007). Vegetation and agriculture are expected to change in response. These changes are expected to increase household vulnerability to drought and flood, with devastating effects on the poor and already vulnerable (Hudson and Jones, 2002).
- Slow generation, adaptation, adoption and effectiveness of AKST. Effective AKST will be expected to provide solutions that will enable the poor to adapt to changing circumstances and aid public and private assistance organizations to make adaptation possible. Food insecure populations will need to be informed of future climate prospects and better supplied with resources for water conservation and development of drought-tolerant crops.

New and innovative ways of managing water in agriculture are needed to facilitate continued agricultural growth and to release more water for other uses, including for the environment. AKST has contributed to driving changes in four water management arenas and will be expected to do more to address emerging challenges:

- Conserving vital water catchments, reducing water pollution and reversing the degradation of aquatic ecosystems.
- Enhancing water supply by capturing usable flows and tapping marginal water resources.
- Ensuring equitable distribution and use of water its derived benefits, with the highest returns to society.
- Increasing net benefits per unit volume of water by reducing nonbeneficial uses and allocating water to high value uses.

3.4.2.2 Protecting water resources and related ecosystems

Agricultural growth in many parts of SSA has come at the expense of forest, grassland and wetland ecosystems and has contributed to degraded water and ecosystems. Africa lost 55 million ha to deforestation from 1980 to1995 (FAO, 1997). Cameroon has lost nearly 2 million ha and Democratic Republic of Congo may be losing 740,000 ha annually. In just 100 years, Ethiopia's forests have declined from 40% to 3% of the land area. Conversion of swamps and marshlands to cropland and urban industrial establishments threatens the integrity of aquatic ecosystems and their ability to provide ecological goods and services (MA, 2005). Fisheries are under threat from declining river flows, fragmented rivers, shrinking wetlands, water pollution and overfishing. Poor agricultural land use is blamed for eutrophication (Bugenyi and Balirwa, 1998).

Inappropriate land management in water catchments causes most soil erosion. Soil loss ranges from 1 to 56 tonnes ha^{-1} yr^{-1} (Okwach, 2000; Liniger and Critchley, 2007). Sub-basin soil loss varied from 12 to 281 tonnes km^{-2} yr^{-1} and suspended sediment discharge was as high as 200 kg s^{-1} during peak flow soil and water conservation measures reduced soil loss. Soil loss for a conventionally plowed maize field with no mulch was 32 tonnes ha^{-1}, 10 tonnes ha^{-1} with 50% mulch and 2 tonnes ha^{-1} with 100% stover mulch from the previous season (Okwach, 2000). In northern Ghana and Burkina Faso the adoption of savanna and Saharan ecoagricultural practices reduced soil loss by 10 to 40% and increased groundwater recharge by 5 to 20%, depending on their effectiveness and adoption (Tabor, 1995). Appropriate AKST is available that can reduce degradation of water catchments, but its access, adaptation, adoption and effectiveness are limited in most places.

3.4.2.3 Improving water supply through effective capture of water flows and use of marginal water resources

Throughout SSA, pockets of suitable land, water and fisheries could be used more sustainably. Current AKST can tap this potential.This will require technology for water storage, rainwater harvesting, exploitation of aquifers, interbasin water transfers, desalinization, wastewater use, and sustainable and wise use of wetland and forest ecosystems. The challenge lies in creating the conditions for sustainable use of these resources by acquiring use rights and improving market access, incentives and regulation.

The productivity of rainfed agricultural systems in many parts of SSA is low and there is considerable potential for increasing it through AKST. Grain yield in semiarid Africa can be increased from the current 0.5 to 1 tonne to 5 tonnes ha^{-1} by increasing the green water (water from precipitation stored in unsaturated soils) taken up by plants as evapotranspiration (Rockstrom, 2001). The largest improvement in yield and water efficiency is achieved by combining supplemental irrigation with fertilizer application. Water conservation practices that increase available soil moisture can be economically feasible only when nutrient deficiencies are corrected (Onken and Wendt, 1989). Studies on deficit irrigation have shown that applying less than optimal amounts of water can increase productivity (Oweis and Hachum, 2001).

Improving the water supply in rainfed agriculture is required to unlock its potential. Maize yields of resource-poor farmers are generally less than 1 tonne ha^{-1}, whereas farmers who adopt modern technologies (improved seeds, fertilizers, etc.) obtain 1.5 to 2.5 tonnes ha^{-1} (Rockstrom et al., 2007). This is partly because of high runoff and evaporation losses. Where AKST has been adopted, soil water is enhanced and crop performance improved. Mulching in a semiarid environment can increase maize by 35 to 70% (Liniger et al., 1998). In northern Ghana the improved access, adaptation and adoption of soil and water conservation techniques—stone bunding, mulching, water harvesting, composting and planting neem, acacia and mango trees—contributed to a maize yield increase from an average of 0.200 tonnes ha^{-1} to 1.600 tonnes ha^{-1}. A combination of soil and water conservation practices, fertilizer micro-dosing and an informal inventory credit system that secures a fair price for produce and improves access to inputs has improved the livelihoods of over 12,000 farmers (Tabo et al., 2005). Yields of sorghum and millet increased 44 to 120% while farmer income increased 52 to 134%.

Water harvesting and storage reduces the risk of crop failure. Under such conditions, farmers use few purchased inputs, which further limits attainable yields, even in good rainfall years. Such farming strategies are partly responsible for the low adoption of high-yielding technology, improved management and other AKST. Improved moisture conservation reduces runoff and soil loss, reducing the frequency of water stress on crops. Water harvesting has been shown to reduce risk by 20 to 50%. Small reservoirs and soil and water conservation practices reduced risks associated with climate variability, facilitated the adoption of higher-yielding crop varieties, increased fertilizer use and produced a timelier and better crop (Faulkner, 2006). These improvements led to better resource efficiency, a 40 to 160% increase in maize yield and a 30 to 85% increase in profitability. Expansion of cropland and higher yields are curtailed by the inability to harvest and store rainwater and manage it to enhance biomass.

The strategic placement of livestock watering points facilitates the use of grazing resources that would ordinarily have gone to waste. In the Wajir district of Kenya, 10 to 50% of the grazing resources are underused because livestock lack water points. About 15 to 35% are severely degraded because of livestock concentration around the watering points. Considering the growing demand for livestock products in SSA, enhancing livestock water supply in underutilized grazing areas is highly desirable.

Studies on urban agriculture report the high potential for wastewater irrigation, partly because it has many nutrients and the area that would be watered is close to the market. In Accra, over 800 small vegetable farmers produce vegetables using wastewater. These vegetables, mainly lettuce, are consumed by about 200,000 urban dwellers but could pose a considerable health risk (Obuobie et al., 2006).

3.4.2.4 Fair sharing and benefits from water use

All SSA countries share at least one international river basin and natural transboundary flows are significant in some countries. Not only does the water have to be shared among sectors, it has to be shared among countries. The benefits from water use vary, with higher values seen where there is a comparative advantage. Maximizing the total net benefit from a shared water basin requires planning and an evaluation of the tradeoffs between optimizing total net benefit and enhancing local self-sufficiency.

There is considerable scope to improve the performance of irrigated agriculture. Approximately 40 to 60% of irrigation water in SSA is lost through seepage and evaporation and seepage contributes to soil salinization and waterlogging (UNEP, 2002). Irrigation and drainage projects in semiarid areas are at risk from poor operation and maintenance. The high sediment load in most rivers chokes intake works and silt is deposited in canals and reservoirs, reducing capacity and making water control structures inoperable. As a consequence, systems operate below capacity and have unreliable supplies, which result in reduced cultivated area, yield decline, farmers shifting to lower-value crops, fewer inputs to reduce risks and reduced investments in maintenance. As a result, small-scale farmers and some government irrigation projects undergo cycles of build–neglect–rehabilitate–neglect and some are ultimately abandoned.

Good maintenance practices can generate positive incremental benefits even under adverse conditions (Skutsch and Evans, 1999). In order to improve maintenance, irrigation planners and managers and policy makers must create policy and institutional frameworks and provide incentives conducive to improved design, planning and operations (IPTRID, 1999).

3.4.3 Biodiversity

Natural ecosystems provide many services essential to human existence (Jackson et al., 2007). Increased species diversity provides more opportunity for species interactions, improved resource use, and ecosystem efficiency and productivity. For example, biodiverse grasslands outperform the best monocultures, producing better and storing more carbon (Tilman et al., 2002). In general, there is a positive correlation between species richness and productivity, and ecosystem resilience to drought (Tilman, 1997). In SSA, diversified farming reflects local knowledge and farmer innovations (Crucible II Group, 2000). AKST has built on traditional practices. For instance, live fences contribute to the ecological integrity of agricultural landscapes (Harvey et al., 2005) in the Sahel. Research in Uganda found species utility and occurrence is related to farmer socioeconomic status (Eilu et al., 2003). Concern for the loss of biodiversity and its impact on food security and productivity is an important driver of AKST. Wild biodiversity contributes significantly to the productivity and sustainability of agriculture, forestry and fisheries, and is addressed directly within some integrated natural resource management strategies (Lemons et al., 2003).

3.4.3.1 *Agrobiodiversity*

AKST has had a fundamental influence on agricultural biodiversity and has affected African production systems and development goals. SSA is the center of diversity for several of the world's most important crops, including coffee, sorghum, lentil, wheat, barley, African rice, oil palm, yam and cowpea (IAC, 2004). Over the years, large investments have been made in developing complementary genetic conservation combining in situ and ex situ technology (Damania, 1996). In situ conservation is vital because it provides a pathway for preserving complete biological diversity. It continues important basic necessities, such as medicines, fodder, food cosmetics, industrial products, fuelwood and timber, upon which most humankind depends. Wild species, including relatives of cultivated plants, are crucial in crop improvement programs as sources of genes for disease and pest resistance, environmental adaptability and nutritional qualities. In situ conservation evolved to establish and sustain a broad genetic base, stabilize and maintain populations and present opportunities for expanding agricultural systems (Chang, 1994).

Species conserved in situ with different AKST approaches are likely to have uses as components in industry, medicine or breeding, for cultural uses and biocontrol programs. In situ conservation continues the cultivation and maintenance of landraces on farms, in the areas where they evolved and developed their distinctive properties. Such conservation may provide farmers with the incentive to act as custodians of traditional varieties nurtured in their fields and backyards (Altieri and Merrick, 1987). Crop diversity conserved in situ encourages traditional culture and agriculture. The domestication of trees and crops and their integration into agricultural landscapes has led to diversified production systems and increased agricultural productivity, while helping provide options and averting risks against crop failure.

3.4.3.2 *Tree diversity*

About 10,000 tree species are native to Africa, comprising about a fifth of the world's tropical tree species. Few well-documented germplasm collections of African tree species exist. Exceptions include those for *Acacia karroo, Allanblackia* spp., *Irvingia gabonensis*, *Prunus africana*, *Sesbania sesban*, and *Uapaca kirkiana*. Few molecular genetic taxa have been investigated (Dawson and Powell, 1999). While substantial tree planting has taken place in some areas, it has been limited to a few taxa (Simons et al., 2000; Kindt et al., 2004). Concerns about overdependence on a few taxa have been borne out by pest problems on *Cupressus lusitanica* and *Leucaena leucocephala*. Farmers, however, can only plant what is available, and the tree germplasm available is inadequate.

The inadequacy of tree germplasm in SSA has been recognized for some time. The FAO Global Programme for Conservation and Management of Forest Genetic Resources set up in the 1960s and 1970s brought the attention of governments and donors to the situation in Africa. The approach taken was to provide support for breeding programs of industrial tree species, especially tropical pines and eucalypts (Barnes and Simons, 1994). Both international and national government tree seed centers were established to multiply and distribute improved germplasm to plantations. The 1980s and 1990s saw the interest in social and development forestry trigger the formation of other central national tree seed centers, often working with many multipurpose tree species. Subsequent monitoring, however, revealed that these centers only covered the formal market, which in several countries was estimated at less than 10% of the tree seed market (Lilles et al., 2001). This shortfall in achieving development objectives was apparently because tree seed centers had been established by national tropical forestry action plans, which had largely ignored emerging informal and on-farm activities.

3.4.3.3 *Livestock*

Various domesticated livestock species were introduced to Africa between 5000 BCE and 2300 BCE, mostly from western Asia and the Near East. Over the centuries, African farmers and herders selected animals for specific attributes. There are currently more than 50 types of cattle and several breeds of sheep and goats.

AKST ex situ innovations for conserving genetic resources are developing improved varieties and building upon the variability of on-farm varieties. The conservation of germplasm has ensured the long-term availability of this vital raw material. Technology for ex situ conservation includes gene banks as sources of diversity for crop improvement programs. Currently, a large number of crop varieties are held in gene banks throughout Africa, mainly through partnerships involving CGIAR centers and NARIs. Examples include in vitro gene banks for banana in Gitega, Burundi, and ex situ seed banks developed with the assistance of Bioversity International in Ethiopia, Kenya, Sudan and Zambia, plus other countries. Agricultural science and technology has been used to characterize and evaluate the conserved genetic resources of germplasm, using widely available descriptor lists developed by different CGIAR centers and NARS.

Farmers over the millennia have helped protect agrobiodiversity. However, germplasm in gene banks has, in many instances, been reintroduced into agricultural production where on-farm varieties were lost because of civil strife or other socioeconomic conditions. Maize and sorghum germplasm were reintroduced into Somalia agriculture after traditional varieties were lost during the protracted conflicts (Friis-Hansen and Kiambi, 1997).

Ethnoveterinary studies documented an elaborate classification of cattle disease and remedies among East African pastoralists. In Nigeria, one survey identified 92 herbs and plants used in ethnoveterinary medicine. A similar case was found in the Sahel: the Tuareg know the timing of the sheep reproduction cycle and its relationship to the seasonal cycle, giving them considerable control over stockbreeding. The Tuareg selectively use penile sheaths on rams to ensure that lambs are not born at the end of the dry season, when the nutrition for ewes is poor.

3.4.4 Biosafety

Concerns and debates about GM crops center around four major areas of concern: the threat to human, animal and environmental health; food and feed safety; the socioeconomic impact on small-scale farmers and developing country communities; and ethical and religious concerns. Of the 11 developing countries growing genetically modified (GM) crops only South Africa is in SSA (James, 2007). South Africa grew 1.4 million ha in 2006—a 180% increase over the 0.5 million ha planted in 2005. South Africa realized US$164 million from commercializing GM crops (Runge and Ryan, 2004).

- Environmental concerns center on the threat to biodiversity from continuous monoculturing of GM crops, the reduced need for landraces and the effect of modern agronomy on natural biodiversity. There might be increased fitness and weediness in plants not previously weedy (Johnson, 2000). The long-term stability of the transgene is not known. The effect on other organisms, the abiotic effect of the transgene on other organisms in the soil, air and water, and the long-term effects are not clearly understood (Wolfenbarger and Phifer, 2000).
- Food and feed safety concerns relate to the toxicity that might result from expression of the transgene or the potential allergies it might cause (Metcalfe et al., 1996; Nordlee et al., 1996). The transgene might affect the nutritional content of the food or widespread use of antibiotic resistant genes used as markers could lead to increased resistance in clinical use (Hare and Chau, 2002).
- Economic concerns stem from worries that multinational companies will gain control over the food chain by patenting a technology, resulting in limited access by both small-scale farmers and developing country scientists. Furthermore, patenting the technology results in altered farming practices where the farmers can no longer save seed for replanting. There is concern that globalization and unfair trade practices such as the production of inexpensive good-quality commodities in industrialized countries could lead to income inequalities and threaten livelihoods in marginalized communities. The dilemma for Africa is how to enhance existing local and traditional AKST, including postharvest technologies and market—roads that will improve SSA food security, livelihoods and rural development—without exacerbating SSA's deteriorating terms of trade. The vast majority of food and feed crops Africans consume are grown with almost no intergovernmental or donor support from farmer-saved seed and farmer-developed varieties. For this reason, the African Group at the World Trade Organization (WTO) TRIPS Council have supported maintaining patent exemptions on life forms (article 27.3b) and have sought to protect the use of traditional AKST at World Intellectual Property Organization negotiations. Africa has also opposed attempts to restrict farmers' right to save and exchange seeds at implementation negotiations of the Convention on Biological Diversity and the International Treaty on Plant Genetic Resources for Agriculture and Food.
- Social concerns include a consumer's right to choose whether to use or avoid GM food, religious and ethical concerns relating to dietary preference, the inability of farmers to save and replant seed, and threats to organic farming practices. The issue of labeling is an ongoing debate that has long embroiled countries. Some developing countries, including the SSA countries of Ghana, Kenya, Senegal and Swaziland in particular, prefer labeling GM foods (ICSTD, 2005). For informed decision making, labeling will have to take into account language, literacy level and public awareness.

Most of Africa's crop exports that could be labeled as "possibly GM" and potentially shunned from European markets, in fact go to other African countries—80% of these crops from Kenya, 85% from Tanzania, 95% from Zambia and 99% from Uganda have destinations within the continent (Paarlberg et al., 2006). Uganda's exports to the EU declined, from US$309 million in 1997 to US$185 million in 2002, and the share directed to the Common Market for Eastern and Southern Africa (COMESA) increased (Uganda Export Promotion Board, 2005). Therefore it is possible that most crop production that might at this time include GMOs could be traded within Africa itself. For as long as that is true, then the concern will be market rejections of GM products produced in Africa by Africans, rather than rejection by Europeans, Asians and those in the Middle East. Sub-regional agreements that promoted the trade of GM crops between these countries might in the short term preserve the ability of African GM producing countries to export their goods to other countries on the same continent (Paarlberg et al., 2006), but would neither be a guarantee of consumer acceptance nor of long-term competitiveness in possibly larger overseas markets that pay a premium for non-GM goods. The rationale for sub-regional agreements might not be convincing for countries such as Egypt, Ethiopia and Uganda who already export their goods outside of (non-Arab) Africa (Paarlberg et al., 2006). For example, by 2005 Uganda's exports to Europe climbed to US$249 million, a 44% increase over 2004 (Uganda Export Promotion Board, 2005), and Europe remains the single largest destination for Uganda's exports.

Potential risks will need to be assessed and managed safely, and in a manner that inspires public trust in the regulatory systems (Persley, 2003). However, in most countries the capacity to address risk assessment, risk management and GMO testing is limited. This limitation could be addressed by harmonizing guidelines, legislation and best practices for regulating the safe use of biotechnology in agriculture. It must be considered in the context of pooling limited resources and using the available technical expertise in biosafety (Persley, 2003). The draft report of the High-Level African Panel on Modern Biotechnology of the African Union (AU) and the New Partnership for Africa's Development (NEPAD) suggests a regional approach based on practical experience and shared expertise.

The SADC guidelines for GMOs have countries committing themselves to a harmonized approach in handling and moving GM food aid across boundaries (Balile, 2003). Countries with no national biosafety laws have been encouraged to use the African Model Law (AML) (Ekpere, 2002). Critics of the law state that it cannot be implemented in its present form as it would complicate countries' attempts to comply with the provisions of the Cartagena Protocol on Biosafety (CPB) (Africabio, 2001). Specifically it was argued the AML is retrogressive in that it broadens the scope of products under review. Products that SSA states currently consider safe will need to be reevaluated. Implementing the law would not be compliant with stipulated timeframes for decision making under the CPB, nor would it be compliant with labeling requirements stipulated under CODEX, or with science-based decision making under WTO. With the GMO debate ongoing, public awareness education and participation remain paramount (Leshner, 2007) and will need to be pursued in a fully participatory manner.

In order for the agricultural sector to modernize, policies favorable to the adoption of new farming techniques and technologies for increased efficiency and productivity must be in place. The adoption of biotechnology, for example, would have to be accompanied by safety and enforcement measures. National biosafety regulatory structures should guide countries on all aspects of biosafety concerning GMOs—their import, export, development, production, use, application and release into the environment. Country strategies need to allow for the implementation of international and national agreements and legislation. A major challenge to the implementation of new legislation is the lack of capacity in terms of equipment, skilled human resources, and funding as well as limited public awareness. Functional infrastructure to support the safe development and use of modern biotechnology is on the verge of rapid expansion. As far as Africa is concerned, capacity must be built urgently to be able to assess and manage risk, and to detect GMOs and their products.

3.4.4.1 Regional biotechnology and biosafety initiatives

Several regional initiatives have the objective of safely applying science and technology including biotechnology and biosafety. Kenya, Tanzania and Uganda are currently using interim biosafety systems to regulate research on GMOs. In Kenya, the National Council for Science and Technology is the government agency responsible for overseeing the implementation of the biosafety regulatory systems. In Uganda it is the National Council for Science and Technology. In Tanzania, the Agricultural Biosafety Scientific Advisory Committee is a competent authority of the Ministry of Agriculture, Food Security and Cooperatives (Abdallah et al. 2005; Jaffe, 2006). Efforts are under way in each of the East African countries to develop national biosafety frameworks through UNEP-GEF projects.

The Grupo Inter-Institucional Sobre Bio-Seguranca was formed in August 2002 to coordinate all biosafety activities in Mozambique, while the Instituto Nacional de Investigaçao Agraria (National Institute of Agronomic Research), now known as the Instituto de Investigaçao Agraria de Mozambique (Mozambican National Research Institute for Agriculture), was appointed as the implementing agency. A decree for the transboundary movement of GMOs has been proposed. Mozambique is now looking at the technical issues surrounding GMO testing.

Angola has a decree on transboundary movement and importation of GMOs in the country. The government does not wish to engage in GM research until a legal process is in place. The country has signed the CPB but has yet to ratify it. São Tome and Principe has convened a meeting to begin drafting a national strategy on biosafety. Plans are under way to sign and ratify the protocol, although the country is concerned about its limited human resource capacity to carry it out. Cape Verde is yet to ratify the CPB; Guinea Bissau ratified on 1 March 2005.

Malawi signed the CPB in 2000, but has yet to ratify it. Malawi adopted the Malawi Biosafety Act in 2002, predominantly in response to the GM food aid debate. The government's position to date has been that GM food aid can be accepted in milled form. The act is administered by the National Research Council of Malawi, soon to become a commission. Draft generic biosafety guidelines have been developed to guide the implementation of biosafety activities. A GMO Regulatory Committee has been established, which advises the council on issues related to biotechnology, genetic engineering and human gene therapy. A national policy on biotechnology and biosafety has been developed, stakeholder consultations have been held and the policy underwent the final rounds of review for submission to the cabinet in March 2007.

The South Africa National Biotechnology Strategy was launched in 2001 in recognition of the fact that few products were reaching the marketplace. The underlying principles highlighted in this document were economic growth, taking advantage of South Africa's comparative advantage, using the existing capacity and reviewing national priorities in light of global trends. Common technology platforms, collectively known as Biotechnology Regional Innovation Centers (BRICS) have been formed, and so has the National Bioinformatics Facility (Crouch et al., 2003).

3.4.4.2 Regulatory and legislative framework

The GMO act (Act 15), which was put into action in 1999 (enacted in 1997) in South Africa, is administered through the Ministry of Agriculture. An Executive Council, with representatives from the Department of Arts, Culture, Science and Technology, Trade and Industry, Labour, Water Affairs and Forestry processes and takes the final decision on GMO applications. The Advisory Committee is a body made up of scientists who advise the Executive Council, the Registrar and the general public on GMOs. The Registrar and the Inspectorate oversee the review of applications, field trials and inspection of laboratory facilities, and they advise on biosafety and issue permits. During the 1990s South Africa processed its applications through the South African Committee on Gene Experimentation, which was superseded by the GMO Act in 1999.

The country has an intellectual property system in place (Wolson, 2005) and is signatory to various international treaties and conventions. The legislation is similar to that of British and European legal systems. It has a representative number of patent attorneys, but only a few are qualified in biotechnology. The South African Patent Office is being upgraded from a receiving office to one for examination; it processes over 70,000 patent applications annually. This figure far exceeds the number processed annually by ARIPO (700-1000), the regional patent office for Anglophone countries. Given this level of activity by ARIPO, South Africa may be more inclined to establish a continental office inclusive of both Anglophone and francophone countries, than to seek to join the present ARIPO.

South Africa's commercial market value for GM maize, cotton and soybean was estimated at US$146.9 million in 2004 (Runge and Ryan, 2004). There is an enabling environment for receiving and evaluating transgenic crops. Since 2003, South Africa has participated in the UNEP-Global Environment Facility project to bring the biosafety regulatory framework in line with the CPB. South Africa acceded to the protocol in 2003 even though it was not a signatory. As a party to the protocol and as a major producer, South Africa will need to comply with the CPB. Particularly as the country becomes a major exporter of GM grain or stock feed to some markets in sub-Saharan Africa in the near future. At stake will be the need for an advance informed agreement for commodity exports with importing countries that are parties. However, GM cotton lint, crushed maize and soybean for stock feeds will not require special handling under the protocol as these are nonliving modified organisms.

3.5 Trade, Markets and Globalization

Local, regional and global agricultural markets drive economic development and agricultural growth by providing an incentive for allocating resources to ensure the highest value production and maximum consumer satisfaction (Townsend, 1999).

3.5.1 Local trade and markets

Inadequate local trade and market conditions adversely affect agricultural productivity, profitability and investment. Weak input and output markets result in inputs that are expensive and not consistently available, as well as low producer prices; weak financial sectors limit access to credit for small-scale producers. SSA has traditionally suffered from weakness in these areas.

Sub-Saharan African markets are changing (Rosegrant et al., 2001); and the continent's rapid urbanization and other economic, climate and demographic shifts will have significant implications for SSA agricultural production and markets. For example, the effects of urbanization on both the quantity and types of agricultural products demanded by domestic consumers may create new incentives and opportunities for SSA agricultural producers, wholesalers and retailers. The transition from subsistence-oriented agriculture to commercial agriculture for markets that are increasingly urban requires development of better infrastructure such as roads and markets.

Once market channels develop, transport and transaction costs usually decline.

3.5.2 Regional trade and markets

Sub-Saharan African countries are forming and strengthening regional trade arrangements and agreements. Regional trade arrangements offer opportunities for markets that are more reliable and therefore more favorable to foreign direct investments (Summers, 1991). Regionalization also presents an opportunity for individual countries to deal cooperatively with infrastructural problems, limited institutional capacity lack of physical and human capital, limited natural endowments, geographical barriers, and unfavorable policy environments (Richards and Kirkpatrick, 1999).

In general, SSA countries have individually been performing poorly with respect to economic growth. For example, non-oil exports, mostly agricultural, earned US$69 billion in 2000, instead of the projected US$161 billion they would have earned if agricultural exports had continued at 1980 levels (Sharer, 2001).

SSA countries are looking to regional integration for enhanced trade and investment, economic efficiency, economic growth and regional stability to reverse the weak growth performance of the past two decades. The move to regional trade in SSA can be seen as a defensive response to the perceived marginalization of Africa in globalization and multilateral trade forums (Mistry, 1995).

The major regional trading areas in SSA are (1) the Economic and Monetary Union of West Africa (UEMOA), (2) the Economic and Monetary Community of Central Africa (CEMAC), (3) the Economic Community of West African States (ECOWAS), (4) the Southern African Development Community (SADC), and (5) the Common Market for Eastern and Southern Africa (COMESA). UEMOA and CEMAC are both preferential trade areas and monetary unions; the others are preferential trade areas only. The East African Community is a regional grouping that is increasing in significance; in 2007 it expanded its membership to include Rwanda and Burundi. The two countries bring an additional 15-20 million people to the EAC market, and they are a direct link to the Democratic Republic of Congo. Regional trade has increased more in some SSA trade organizations and bodies than in others: UEMOA, CEMAC and SADC have seen more trade increase than ECOWAS while COMESA has registered the least.

Regional trade agreements that combine both a preferential trade agreement and a currency union component are likely to be efficient in increasing intraregional trade (Carrere, 2004). It is for this reason that COMESA, established in 1983 as a preferential trade area, has ambitious plans for full economic integration, including the free movement of people by 2014 and currency union by 2025 (Carmignani, 2006; Gupta and Yang, 2006).

The potential for regional trade is huge. Intraregional trade development in agriculture, formalizing existing informal trade, value addition and ICT are all largely unexploited trade opportunities. Sub-Saharan African countries currently import food products equivalent to 14% of global imports (Yeats, 1998), though they have a comparative advantage in producing and exporting these commodities. Additional benefits are also likely to accrue from formalized existing informal trade in food and food products between countries that share common borders.

The trade potential from processing and value addition and in services from medical to education to ICT is enormous. African economies that produce commodities could benefit from moving up the value chain and process foods they produce rather than export raw materials. For example, Ghana, the world's second largest cocoa grower, has moved slowly into making chocolate; Ethiopia, which has been growing coffee for a thousand years, still exports raw, unprocessed beans. Rwanda, which has moved into specialty coffee, exports less than 10% of its coffee fully washed. This is despite the fact that these countries face no European Union tariff on chocolate and on roasted and ground coffee. A major limitation to processing and value addition in SSA may be attributable to the lack of a business climate conducive to investment and good transportation infrastructure. These obstacles will likely require regional solutions, especially for smaller economies, which would benefit from the promotion of regional trade. It will be difficult for sub-Saharan Africa to participate more profitably in global trade without establishing a regional presence and national and regional infrastructure for value addition for local producers.

Factors that affect regional trade groupings and make them less competitive in SSA include lack of needed infrastructure, unfavorable geography and low GDP. Another factor that affects the competency of regional trade arrangements in SSA is the number of overlapping initiatives, such as in eastern and southern Africa.

In SSA regional trade arrangements have (1) created incentives for removing restrictive trade practices and licensing procedures, (2) streamlined customs procedures and regulations, (3) integrated financial markets, (4) simplified transfers and payment procedures, and (5) harmonized taxation. Countries have gone even further, seeking to harmonize investment incentives, standards and technical regulations, as well as policies relating to transportation, infrastructure, labor and immigration.

Regional economic integration may help prevent SSA from becoming more marginalized as a result of globalization and competition with trade and economic blocs in other parts of the world. Regional economic integration can improve the success with which SSA articulates its concerns and prevent international agreements that may disadvantage SSA. An assessment of the effect of economic communities on trade and growth in SSA shows that regional agreements are far from reaching their intended goal of integration (UNECA, 2005). Achieving the highest level of integration are SACU, UEMOA and EAC. The most successful regional integration has been where a relatively compact geographical neighborhood coincides with other essential elements such as colonial past, language and macroeconomic parameters like currency and customs union.

Empowerment of regional economic corporations can improve the negotiating power of SSA and help meet the international sanitary and phytosanitary standards that will allow for more participation in international trade. Scientific and technological advances can also be shared through regional economic cooperation.

3.5.3 Global trade policy, market infrastructure, links and market barriers

Globalization is a major driver shaping the evolution of markets for agricultural goods, and thus the evolution of AKST and the adoption of agricultural technologies.

3.5.3.1 Trade policy and global market dynamics

International trade and prices influence growth in SSA, because most SSA economies export raw agricultural commodities. Agriculture accounts for about 40% of exports (Townsend, 1999). The trends of world prices and especially of primary crops have been fluctuating. This historical downward trend negatively affected the growth of SSA economies.

There is no doubt that trade is an effective source of growth for SSA. However, it requires improved efficiency in the trading sectors. Distortions in WTO regulations and the SSA position as a supplier of raw materials have contributed to the low levels of economic growth. SSA farmers will face reduced competition if subsidies on exports from European and other developed countries are removed. Similarly, removing the taxes that most African governments impose on food production and consumption could stimulate farm investment and lower food prices (IAC, 2004). The US decision in May 2002 to increase its domestic agricultural subsidies by 67% will not enable SSA to increase agricultural exports.

SSA countries tend to enjoy little leverage within the global economy. One view is that leverage can best be strengthened through regional cooperation. This is to be in parallel with globalization within the scope of WTO. The aftermath of decisions made in previous WTO meetings has disappointed African countries. Benefits of African, Caribbean and Pacific–European Union (ACP-EU) negotiations have been negligible. Although world market prices for some commodities have risen recently in general during the last two decades, the adoption of internal and international market liberalization polices and other associated agricultural sector policies promoted by international financial institutions has led to a catastrophic fall in the prices of many of the agricultural products exported, especially by East and Central African countries due to systemic overproduction stimulated by components of structural adjustment programs. The major flaw in this strategy was that similar advice was given to almost all tropical countries at the same time; for example, coffee-producing countries were encouraged to boost coffee production and sugar producers to produce more sugar; crops in which these countries had a comparative advantage. This resulted in overproduction of these commodities, which caused prices to plunge in the international markets and less income to be earned as more commodities were produced.

East and Central Africa countries are highly dependent on the production of cash crop commodities for employment, economic growth and export revenue. Countries that produce and export raw commodities such as coffee, sugar, tea and cotton through small-scale production systems are unable to create new jobs or reinvest in alternative market sectors. Thus countries and individual farmers who rely on cash crop production for revenue are obliged to continue to grow and sell these commodities, no matter how low prices fall (Robbins and Ferris, 2003).

While the neo-liberal principles of structural adjustment programs led to trade liberalization in many countries with exchange rate adjustments, a decrease in trade tariffs and abolishment of parastatal marketing boards left African producers facing inequities in international trade with mainly the EU, the United States and Japan, which continued to protect their markets against imports from developing countries. The support and trade protection measures of industrialized countries reduced net agricultural exports of developing countries by nearly US$40 billion, resulting in an annual loss to agriculture and agroindustries in developing countries overall of US$24 billion (Orden et al., 2004). If industrialized country support policies and trade barriers were removed the value of SSA net agricultural exports might increase by one-third, increasing the value of agricultural GDP by about US$2 million (Orden, 2004).

Trade has significant potential to benefit the poor but only if enabling policies and institutional infrastructures are in place. Advocates of market liberalization, however, concede that the notable exceptions to this rule are African countries where growth is not evident. Globalization has further exposed and intensified existing structural and institutional weaknesses in some SSA countries. The expanding global market requires consistent economic policy formulation and implementation and transparency in governance.

3.5.3.2 Market infrastructure, links and barriers

Robust market infrastructure is important, and will underpin Africa's ability to benefit from new trade opportunities. New export opportunities are emerging for nontraditional export crops, livestock production and processed foods, but mostly for producers who are well connected to markets and who can meet quality standards. To capitalize on this potential requires regional, national and local markets to be linked more explicitly than they are currently (Diao et al., 2005).

The following elements comprise a strategy to stimulate broad-based growth in agribusiness by developing micro- and small-enterprise agricultural production and marketing (Steen et al., 2005):

- A policy and regulatory environment that provides incentives for small-scale producers and micro- and small-enterprise participation in markets.
- Vertical links—and systems of vertical coordination—that take a long-term, inclusive approach to working with small-scale producers and small and medium enterprises.
- Horizontal links and cooperation among like firms to reduce transaction costs and achieve external economies.
- Upgrading of both the chain and firms in the chain by promoting product and process innovations, improving the flow of information and learning, and addressing systemic constraints.
- Support of markets to ensure sustainable access to finance, business services and inputs.
- Competitive strategies that bring these elements together into commercial solutions that offer developmental benefits, i.e., national branding, penetration of niche markets and social marketing strategies.

Globalization and the increased competition that accompanies it requires African agricultural producers to build their capacity to comply with exacting standards of food quality and safety, as well as production (e.g., in markets for organic produce) and differentiate their products from those of their competitors to compete favorably in industrialized country markets.

This requires an AKST system and a market infrastructure that meets producers' needs for information about these standards and information about market demand and quality. Stronger institutions are needed for technical assistance—producer organizations and regulatory bodies, and also private sector entities such as exporters that provide technical assistance commercially or as an embedded service. These organizations can speed market development by helping develop processing systems that enable producers to conform to established standards and quality control and that facilitate quality certification. Legal and regulatory environments are needed that ensure contracts are enforced and that there are efficient channels for market information and product promotion. Also needed are ancillary business services such as credit and other financial services, risk mitigation in the form of crop or rain insurance, transportation and storage services, accounting and business training services, and price information services, as well as policymaker commitment to market reform and effective marketing institutions. Key to the AKST system is an information infrastructure that can convey information related to both production and marketing of agricultural products, in all appropriate languages and media.

On the production side, information needs include everything from meteorological information specific to distinct agroecological zones, knowledge about crop varieties and management, soil and water conservation, animal husbandry, and agricultural technologies and inputs, to information about credit availability (including supplier credit for fertilizer or feed, etc.), postharvest techniques, processing and value-adding techniques, and other extension assistance.

On the marketing side, information needs range from trade literacy and knowledge of market demand for current commodities and potential opportunities for prospective commodities to processing standards and means of compliance, price information, and so on. The infrastructure for marketing agricultural products includes institutions through which information can flow and which facilitate trade in agricultural commodities. These institutions include ministries of agriculture, producer organizations and cooperatives, bureaus of standards, and private sector providers of business services offering technical assistance in quality control and standards as well as market links. In Africa, these institutions are often weak and underfunded.

Strong market infrastructures include formal and contractual as well as informal links among participants all along the various value chains through which agricultural products are financed, created, processed, traded and consumed. Producer organizations are also an important part of the market infrastructure, given the small scale on which many agricultural products are produced and their consequent disadvantage in the marketplace in the absence of a means of pooling products and consolidating the marketing of those products.

Microfinance is an essential aspect of sub-Saharan Africa's agricultural market infrastructure. Much of Africa's agricultural output is generated by small-scale producers and other microentrepreneurs. Microfinance—financial services whose scale matches the needs of micro- and small-scale producers—is therefore the way agricultural producers are able to expand their production, buy fertilizer and other inputs, adopt new technologies, and smooth seasonal fluctuations in household expenses and enterprise income. Microfinance introduces flexibility into small-scale and microproducer investments and asset building. Newer financial services and products, such as crop or rain insurance, are also critical to reduce the risk associated with adopting new technology, innovating production and marketing methods. Credit terms tailored to agricultural production and marketing, such as loan repayment terms that track seasonal crop production, are critically important to enable agricultural producers to take advantage of economic opportunities.

Agricultural microfinance includes not only the products and services financial institutions offer, but also credit and other value chain services. Those in the value chain respond to different drivers of credit supply and demand than do financial institutions. They can accept more risk, and they have more information about the risks and likely benefits associated with particular agricultural endeavors. They also extend credit differently, e.g., through advance purchases, grace periods for payments for inputs, and embedded services that carry no direct costs.

Supply and demand of rural and agricultural credit is constrained by several factors (Chalmers et al., 2005):

- Distance from the financial institution's branch, low population density and sometimes difficult terrain increase the effort involved in reaching clients and push up transaction costs, which in turn decrease the financial institution's margin and incentive to reach rural and agricultural clients; when transaction costs are transferred to clients, they suppress demand because of the high cost of borrowed funds.
- Fluctuations in income for producers increases the risks associated with credit. Borrowers are less certain about their ability to repay than they would be if their income were more consistent, and lenders are less certain that they will be repaid in accordance with loan terms. Moreover, traditional and most prevalent credit products are not tailored to agricultural production cycles, so repayment often begins before harvest or during a low season, which can increase the risk that producers will default—a negative outcome for both borrowers and lenders.
- Agricultural production can be risky due to factors such as variability in climate and weather conditions, quality of seed or stock, availability of seasonal labor. Marketing agricultural produce is likewise subject to exogenous factors. Because repayment depends on yield and ability to dispose of yield at a profit, these uncertainty factors translate into high risk for both borrower and lender.
- Information about borrowers' creditworthiness is not reliably available in most developing countries, particularly in rural areas. This lack of information increases financial institutions' risk when they lend to clients in these areas.
- If collateral is required to obtain credit, many micro- and small-scale agricultural producers have little or no hope of meeting the collateral requirements.
- Inhospitable policy, legal and regulatory frameworks often prevail in rural and agricultural areas of sub-Saharan Africa. For example, land titling may be nonexistent, or it may lend itself to bias, such as when women are responsible for cultivating land to which they are not legally entitled to hold title.
- Low availability of savings services also inhibits agricultural production; lack of rural deposit services or mistrust of them among would-be savings clients, prevents agricultural producers from saving the capital needed to build their assets and increase their productivity (Charitonenko et al., 2005).
- Where they are available, rural equipment-leasing schemes (Rozner, 2006) and other suppliers of credit, as well as remittance services, can address this market failure in formal rural credit, which in turn can aid farmers to adopt new technologies. In addition to credit, crop, weather and geographic-based insurance, which are emerging products in SSA microfinance, can help create safety nets for small-scale producers.

Nonfinancial and business services value chain links. Business service providers in some parts of SSA offer technological solutions that enhance agricultural producers' competitiveness by reducing unit costs of production, improving product quality and adding value at various stages, including on-farm production, postharvest storage and treatment, agroprocessing, marketing and transport. Postharvest losses in Africa are high; substantial improvement in profitability could be gained by improving roads and markets, as well as encouraging private sector investment in research and development at the lower end of the production-to-market chain (Rozner, 2006).

Competitiveness in global markets is generally enhanced when agricultural commodity markets are segmented and product quality, branding, and marketing are tailored to that market segment. Coffee is one example. By changing their processing methods and extending technical assistance to their members, coffee cooperatives in Rwanda are able to sort and process beans in accordance with quality standards set by European and North American markets. They establish market links with roasters who will guarantee a premium price in return for quality-controlled, stable coffee supplies. In some cases, producers have realized additional value through national branding (e.g., Ethiopian Yirgacheffe, Kenya AA). This is an example of how farmers can benefit by applying agricultural knowledge of how to control commodity quality through production and processing to enhance competitiveness and returns in the market for that commodity.

3.5.3.3 International standards for agricultural production

The global rise of supermarkets is an important driver of change in agricultural production. Foreign direct investment in supermarkets and breakthroughs in retail procurement logistics, technology and inventory management have changed the way that agricultural products are marketed in many developing countries. The impact is currently felt mostly in relation to international trade, although there are some implications for local and regional trade. While few countries in sub-Saharan Africa (except for South Africa) host thriving supermarket chains at this time, this trend is likely to spread throughout the region over the coming decades as knowledge transfer makes the cost savings realized elsewhere possible in sub-Saharan Africa, and in response to increasing urbanization.

Currently, the far more significant effect of this trend is on producers in the region who are selling into supermarket chains in global markets. With such a diverse supply base, retailers find it increasingly critical that minimum standards be in place to protect consumers and ensure quality. Consequently, developing-country producers of all sizes must ensure a steady supply of commodities that conform to international quality standards covering everything from variety, color, size and maturity, to odor, cleanliness, packing, mechanical damage and temperature maintenance. International food safety and quality standards can function both to facilitate producers' entry into regional and global markets and to exclude them from those markets, depending on a range of conditions.

A number of public and private food safety and quality standards regulate not only food safety but also environmental impact, occupational health, worker safety and welfare, and animal welfare. Hazard Analysis and Critical Control Point (HACCP) is a collection of food safety standards promulgated internationally by the Codex Alimentarius Commission (FAO/WHO, 1999) and aimed at reducing health risks in production. Other international standards govern classification categories such as organics and fair trade products. Organic and fair trade certification has proved invaluable for producers seeking, and able, to occupy niche markets, for example in origin-branded coffee.

For many sub-Saharan African producers, for whom European markets represent the most accessible export opportunity, EurepGAP (Euro-Retailer Produce Good Agricultural Practices) is the relevant set of sector-specific standards for farm certification for producers wishing to sell fruits and vegetables, flowers and ornamentals, livestock, aquacultural commodities and green coffee into European community markets. EurepGAP's stated aim is to ensure integrity, transparency and harmonization of global agricultural standards of food safety (including maximum residue levels from pesticides), traceability, worker health, safety and welfare, environmental preservation and animal welfare. Certification requirements have spawned private sector certification bodies (EurepGAP maintains its neutrality by empowering other bodies to conduct the actual certification). Currently, EurepGAP is working with over 100 certification bodies in more than 70 countries. It also recognizes other international standard regimes to reduce the burden on agricultural producers of multiple audits (EurepGAP, 2007).

The impact of such standards on the horticulture industry in sub-Saharan Africa is complex. In some countries, increasing adoption of practices required to meet these requirements has resulted in spillover into domestic markets of technology, quality assurance and management of supply chains. Proponents argue that by applying the recommended protocols on good agricultural practice, small-scale farmers not only enjoy a premium market outlet but experience increased income through gains in productivity and yields as well. In Zambia, for example, farmers have embraced EurepGAP standards as good business in terms of tracking inputs (which reduces theft), improving farm management (which results in higher yields), and increasing group bargaining power (which brings better prices). Improvements in worker safety and food safety vis-à-vis pesticides are also reported (Graffham, 2006). In this sense, the requirements producers must meet to enter the market have generated new agricultural technologies and practices, as well as more favorable market conditions for certain products.

Despite the spinoff benefits of the market-driven requirements and technologies, these increasingly rigid standards may have negative effects as well, serving as a form of import protection for domestic industry, particularly when restrictive measures raise the cost of imported produce. Proposed controls on carbon footprints can compromise the competitiveness of African products in European markets, or exclude them from those markets altogether. Moreover, smaller producers sometimes find certification requirements prohibitively costly and are unable to comply because they lack the resources and expertise to maintain the requisite quality management system. They are also sometimes unable to afford the certification charges (including the fees charged by local certification bodies—in Zambia, for example, fees have been as high as those charged by international certifiers). In fact, at present, the costs associated with training, infrastructural development, testing and analysis, pre-audit inspections, and certification are largely funded by donors. It is unlikely that the private sector will assume these costs in the near term. Some international development agencies (funded by multilateral and bilateral donors) now work with producer associations to help integrate food safety standards into their projects, not only to prepare producers to enter global markets but also to ensure that those not yet ready will adjust their practices in such a way as to avoid exclusion later when they prepare for export (Hobart, 2004). Producers without access to such assistance, however, may find their margins are insufficient to cover the costs of certification and maintenance. In this way, certification requirements to enter export markets may further segment small-scale producers, with new opportunities for the wealthier and reduced competitiveness for the poor.

For countries such as Kenya, however, EurepGAP cannot be ignored, as the EU represents up to 80% of Kenya's market share in horticultural commodities. Comprehensive data on the impact of standards regimes on African agricultural producers are lacking.

While globalization of markets has the potential to open up new export markets for African agricultural products, this potential is conditioned by policies implemented in industrialized-country markets, including agricultural and export subsidies and dumping, and market barriers.

Subsidies and dumping of agricultural commodities produced with or without subsidies close off many options for national and regional sales of SSA agricultural commodities; often even displacing those commodities from domestic markets by introducing unfair competition from cheap, subsidized goods.

Dumping of imported agricultural commodities, poor road and transportation networks and weak market links suppress incentives for SSA producers to expand, adopt new technologies and transform processing operations to comply with export-market standards. In the absence of a market infrastructure through which they can sell their products, African agricultural producers frequently view the risks of adopting new technologies, investing in the production of new goods or increasing production of traditional goods, as too high. These risks are increased as markets liberalize and price volatility ensues. Suppression inhibits production for export and for domestic consumption (since increased production without export opportunities and good markets results in price drops), which in turn impedes efforts to achieve food security for Africa. This competition from subsidized and dumped goods also hobbles African agricultural producers vis-à-vis unsubsidized competition for Africa's traditional export markets from Latin American and Asian producers, in the sense that it renders them less able to compete effectively even in these market relationships (IAC, 2004).

References

Abdallah, R., D. Mackenzie, and G.R. Bamwenda. 2005. Initiating agricultural biotechnology in Tanzania. Trop. Pest. Res. Inst., Arusha, Tanzania.

Abiola, F.A., A. Sere, and J.G. Sawadogo. 1988. Cholinesterase depression among Senegalese crop protection workers exposed to organophosphorus pesticides. Bull. Environ. Contam. Toxicol. 41:483-488.

Africabio. 2001. Submission on the OAU model law on biosafety. Available at http://www.africabio.com/policies/Submission%20OAU%20Model%20Law%20on%20Biosafety%20by%20AfricaBio.htm. Africabio, South Africa.

Ajayi, O.C., S. Franzel, E. Kuntashula, and F. Kwesiga. 2003. Adoption of improved fallow soil fertility management practices in Zambia: Synthesis and emerging issues. Agrofor. Sys. 59:317-326.

Ajayi, O.C, F. Place, F. Kwesiga, and P. Mafongoya. 2006. Impact of natural resource management technologies: Fertilizer tree fallows in Zambia. Occas. Pap. 5. World Agroforestry Centre, Nairobi.

Altieri, M.A., and L.C. Merrick. 1987. In situ conservation of crop genetic resources through maintenance of traditional farming systems. Econ. Bot. 4:86-96.

Anderson, J.R., G. Feder, and S. Ganguly. 2006. The rise and fall of training and visit extension: An Asian mini-drama with an African epilogue? p. 149-172. *In* A.W. Van den Ban and R.K. Samanta (ed) Changing roles of agricultural extension in Asian nations. B.R. Publ., New Delhi.

Anderson, J.R., P.G. Pardey, and J. Roseboom. 1994. Sustaining growth in agriculture: A quantitative review of agricultural research investments. Agric. Econ. 10:107-123.

Andreini, M., W. Andah, C. Balazs, E. Boelee, P. Cecchi, A. Huber-Lee et al. 2005. Small multi-purpose reservoir ensemble planning: Innovative methods. Challenge Program Nile Basin Workshop, Entebbe, 27 Nov-2 Dec 2005.

Andreini, M., N. Van de Giesen, A. Van Edig, M. Fosu, and W. Andah. 2000. Volta basin water balance. Disc. Pap. Dev. Pol. 21. ZEF, Bonn.

Ashton, P.J. 2002. Avoiding conflicts over Africa's water resources. Ambio 31(3):236-242.

AVERT. 2007. Sub-Saharan HIV and AIDS statistics [Online]. Available at http://www.avert.org/subaadults.htm. West Sussex, UK.

Balile, D. 2003. Southern African nations adopt common GM strategy. Available at http://www.scidev.net/News/index.cfm?fuseaction=readNews&itemid=1007 &language=1. Science and Development Network, UK.

Barnes, R.D., and A.J. Simons. 1994. Selection and breeding to conserve and utilize tropical tree germplasm. p. 84-90. *In* R.R.B. Leakey, A.C. Newton (ed) Tropical trees: The potential for domestication: Rebuilding forest resources. HMSO, London.

Bationo, A., F. Lompo, and S. Koala. 1998. Research on nutrient flows and balances in West Africa: State-of-the-art. Agric. Ecosyst. Environ. 71:19-35.

BBC. 2005. Mobile growth "fastest in Africa". Available at http://news.bbc.co.uk/2/hi/business/4331863.stm. BBC, London.

Beer, J., M. Ibrahim, and F. Sinclair. 2005. The history and future of agroforestry research and development: Policy impacts and needs. *In* G. Mery et al. (ed) Forests in the global balance: Changing paradigms. World Series. Vol. 17. Int. Union Forest Res. Org., Helsinki.

Beintema, N., and G-J. Stads. 2004. Sub-Saharan African agricultural research: Recent investment trends. Outlook Agric. 33:239-246.

Beintema, N.M., and G.J. Stads. 2006. Agricultural R&D investments in sub-Saharan Africa: An era of stagnation. ASTI Background Rep. IFPRI, Washington DC.

Bellon, M.A. 2006. Crop research to benefit poor farmers in marginal areas of the developing world: A review of technical challenges and tools. CAB Rev.: Perspect. Agric. Vet. Sci. Nutr. Nat. Res. 1(70).

Bhattarai, M., and A. Narayanamoorthy. 2003. Impact of irrigation on agricultural growth and poverty alleviation: Macro level analysis in India. Available at http://www.iwmi.cgiar.org/Assessment/files_new/publications/Workshop%20Papers/TATA_2003_Bhattarai.pdf. IMWI-TATA Water Policy Prog., Sri Lanka.

Boffa, J.M., L. Turyomurugyendo, J.P. Barnekow-Lilleso, and R. Kindt. 2005. Enhancing farm tree diversity as a means of conserving landscape-based biodiversity. Mount. Res. Dev. 25:212-217.

Brown, L.R., H. Feldstein, L. Haddad, C. Pena, and A. Quisumbing. 1995. Generating food security in the year 2020: Women as producers, gatekeepers and shock absorbers. 2020 Vision Brief. IFPRI, Washington DC.

Brush, S.B. 2000. The issues of *in situ* conservation of crop genetic resources. p. 3-26. *In* S.B. Brush (ed) Genes in the field: On-farm conservation of crop diversity. Lewis Publ., Boca Raton, IDRC, Ottawa, IPGRI, Rome.

CA. 2007. Water for food, water for life: A comprehensive assessment of water management in agriculture. Earthscan, London and IWMI, Colombo.

Carmignani, F. 2006. The road to regional integration in Africa: Macroeconomic convergence and performance in COMESA. J. Afr. Econ. 15:212-250.

Carrere, C. 2004. African regional agreements: Impact on trade with or without currency unions. J. Afric. Econ. 13:199-239.

Chalmers, G., B. Lennon, L. Villeda, L. Heron, E. Pelican, S. Charitonenko et al. 2005. A fresh look at rural and agricultural finance. RAFI Note 1. Available at http://www.microlinks.org/ev_en.php?ID=13979_201&ID2=DO_TOPIC. USAID, Washington DC.

Chang, T.T. 1994. The biodiversity crisis in Asia crop production and remedial measures. *In*

C.I. Peng and C.H. Chou (ed) Biodiversity and terrestrial ecosystems. Inst. Bot., Academia Sinica Monograph Ser. No. 14. Academia Sinica, Taipei.

Charitonenko S., L. Heron, G. Chalmers, B. Lennon, and M. Miller. 2005. Innovations in rural deposit mobilization. RAFI Note 9. Available at http://www.microlinks.org/ev_en.php?ID=13979_201&ID2=DO_TOPIC. USAID, Washington DC.

Chema, S., E. Gilbert, and J. Roseboom. 2003. A review of key issues and recent experiences in reforming agricultural research in Africa. Res. Rep. 24. ISNAR, Washington DC.

CGIAR Science Council. 2004. Synthesis of lessons learned from initial implementation of the CGIAR Pilot Challenge Programs. Ann. Gen. Meet., Mexico, Oct 2004. CGIAR Secretariat, Washington DC.

Clive, J. 2006. Global status of commercialized biotech/GM crops. Brief 35. ISAAA, Ithaca NY.

Cooper, P.J.M., J. Dimes, K.P.C. Rao, B. Shapiro, B. Shiferaw, and S. Twomlow. 2006. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: A dress rehearsal for adapting to future climate change? Global theme agroecology. Rep. 27. ICRISAT, Nairobi.

Crouch J.H., H. Quemada, and J. Webster 2003. Assessment of biotechnology in South Africa. consultancy mission report. USAID, Washington DC.

Crucible II Group. 2000. Seeding solutions 1: Policy options for genetic resources: People, plants and patents revisited. IDRC, IPGRI and Dag Hammarskjöld Foundation, Litopixel, Rome.

Damania, A.B. 1996. Field evaluation and utilization of collections of cereal genetic resources: The current status. Indian J. Plant Genetic Resourc. 9:31-42.

Dauwers, A. 2007. Uganda hosts banana trials. Nature 447:1042.

Dawson, I.K., and W. Powell. 1999. Genetic variation in the Afromontane tree *Prunus africana*, an endangered medicinal species. Mol. Ecol. 8:151-156.

Debouvry, P. 2001. Analyse comparée des systèmes locaux de formation agricole: Enseignement méthodologique pour la rénovation des dispositifs de formation [In French]. Exposé, 20 April.

Degrande, A., K. Schreckenberg, C. Mbosso, P.O. Anegbeh, J. Okafor, and J. Kanmegne. 2006. Farmers' fruit tree growing strategies in the humid forest zone of Cameroon and Nigeria. Agrofor. Syst. 67:159-175.

Dent, D.R., and C.J. Lomer. 2001. The convention of biological diversity and product commercialisation in development assistance projects: A case study of LUBILOSA, CAB Int., Wallingford.

Diao, X., E. Diaz-Bonilla, S. Robinson, and D. Orden. 2005. Tell me where it hurts, and I'll tell you who to call: Industrialized countries' agricultural policies and developing countries. Available at http://www.ifpri.org/divs/mtid/dp/papers/mtidp84.pdf. IFPRI, Washington DC.

Di Falco, S., and J.P. Chavas. 2006. Crop genetic diversity, farm productivity and the management of environmental risk in rainfed agriculture. Eur. Rev. Agric. Econ. 33:289-314.

Diouf, J. 1989. The challenge of agricultural research in Africa. John Crawford Memorial Lecture. Available at http://www.worldbank.org/html/cgiar/publications/crawford/craw5.pdf. CGIAR, Washington DC.

Dixon, J., A. Gulliver, and D. Gibbon. 2001. Farming systems and poverty: Improving farmers' livelihoods in a changing world. World Bank, Washington DC and FAO, Rome.

Dore, T., M. Le Bail, P. Martin, B. Ney, and J. Roger-Estrade (ed) 2006. l'Agronomie aujourd'hui. Editions Quae, Versailles.

Du Guerny, J. 1999. AIDS and agriculture in Africa: Can agricultural policy make a difference? FAO, Rome.

East African Business Week. 2007. Nepad's other easy option. EABW, Kampala.

Eicher, C.K. 2001. Africa's unfinished business: Building sustainable research systems [Online]. Available at http://www.worldbank.org/afr/aftsr/mombasa.doc. Michigan State Univ. and ASARECA, Entebbe.

Eilu, G., J. Obua, K.J. Tumuhairwe, and C. Nkwine. 2003. Traditional farming and plant species diversity in agricultural landscapes of south-western Uganda. Agric. Ecosyst. Environ. 99:125-134.

Ejigu, D., and Y. Mekonnen. 2005. Pesticide use on agricultural fields and health problems in various activities. East Africa Med. J. 82:8:427-432.

Ekpere, J. 2002. The OAU's model law: The protection of the rights of local communities, farmers, and breeders, and for the regulation of access to biological resources [Online]. Available at http://www.grain.org/brl_files/oau-booklet.pdf. Org. African Unity, Lagos, Nigeria.

Estache, A., B. Speciale, and D. Veredas. 2005. How much does infrastructure matter to growth in sub-Saharan Africa?. Available at http://www.ecares.ulb.ac.be/ecare/people/members/veredas/veredas/David%20Veredas%20African%20Infrastructures%20Version%201.pdf. U. Libres de Bruxelles, Belgium.

EurepGAP. 2007. Global partnership for safe and sustainable agriculture. Available at http://www.eurepgap.org/Languages/English/index_html. Euro-Retailer Produce Good Agricultural Practices, Cologne, Germany.

FAO. 1994. Grain storage techniques: Evolution and trends in developing countries. FAO, Rome.

FAO. 1995. The effects of HIV/AIDS on farming systems in eastern Africa. FAO, Rome.

FAO. 1996. Namibia: Women, agriculture and rural development. Available at http://www.fao.org/documents/show_cdr.asp?url_file=/docrep/V9094e/V9094e00.htm. FAO, Rome.

FAO. 1997. Impact du VIH/SIDA sur les systèmes d'exploitations agricoles en Afrique de l'ouest. [In French]. FAO, Rome.

FAO. 2005. State of food insecurity in the world 2005. FAO, Rome.

FAO. 2007. State of the world's forests 2007. FAO, Rome.

FAO/SPAAR. 2002a. History of agriculture research development in sub-Saharan Africa. Spec. Prog. African Agric. Res., FAO, Rome.

FAO/SPAAR. 2002b. Impact of foreign assistance on institutional development of national agricultural research systems. Res. Tech. Pap. 10. FAO, Special Program African Agric. Research, Rome.

FAO/WHO. 1999. Understanding the Codex Alimentarius.. Available at http://www.fao.org/docrep/w9114e/W9114e00.htm. FAO, Rome and WHO, Geneva.

Farrington, J., and G. Gill. 2002. Combining growth and social protection in weakly integrated rural areas. Nat. Resource Perpect. No. 9. ODI, London.

Faulkner, J.W. 2006. Water use, productivity, and profitability of small scale irrigation schemes in Ghana's Upper East Region. MSc. thesis, Cornell Univ., Ithaca NY.

Fay, M., and T. Yepes. 2003. Investing in Infrastructure: What is needed from 2000 to 2010? Policy Res. Work. Pap. 3102. World Bank, Washington DC.

Fibre for Africa. 2007a. SAT3: Opening up affordable bandwidth in Africa. Available at http://www.fibreforafrica.net/main.shtml?conds[0][category........]='About%20SAT3'&als[select]=4018621&als[MYALIAS6]=About%20SAT3. Fibre for Africa, South Africa.

Fibre for Africa. 2007b. EASSy: Opening up affordable bandwidth in Africa. Available at http://www.fibreforafrica.net/main.shtml?conds[0][category........]='About%20EASSy'&als[select]=4018619&als[MYALIAS6]=About%20EASSy. Fibre for Africa, South Africa.

Fibre for Africa. 2007c. Open versus closed approaches to international fibre. Available at http://fibreforafrica.net/main.shtml?x=4911249&als[MYALIAS6]=Open%20versus%20closed%20approaches%20to%20international%20fibre&als[select]=%3Cdiv%3ENo%20item%20found%3C/div%3E. Fibre for Africa, South Africa.

Foster, S., and M. Phillips. 1998. Economics and its contribution to the fight against

malaria. Annals of Trop. Med. Parasitol. 92:391-398.
Franzel, S., R. Coe, P. Cooper, F. Place, and S.J. Scherr. 2001. Assessing the adoption potential of agroforestry practices in sub-Saharan Africa. Agric. Syst. 69:37-92.
Franzel, S., and S.J. Scherr. 2002. Trees on the farm: Assessing the adoption potential of agroforestry practices in Africa. Univ. Maryland, College Park.
Franzel, S., and W. Wambugu. 2007. The uptake of fodder shrubs among smallholders in East Africa: Key elements that facilitate widespread adoption. *In* M.D. Hare and K. Wongpichet (ed) Forages: A pathway to prosperity for smallholder farmers. Proc. Int. Symp. Fac. Agric., Ubon Ratchathani Univ., Thailand. ICRAF, Nairobi.
Friis-Hansen, E., and D. Kiambi. 1997. Re-introduction of germplasm for diversification of the genetic base of the Somali agricultural production system. Project Termination Rep. IPGRI, Rome.
Gallup, J.L., J. Sachs, and A.D. Mellinger. 1998. Geography and economic development. NBER working Pap. W6849. Available at http://ssrn.com/abstract=145013. Social Science Research Network.
German, L., H. Mansoor, G. Alemu, W. Mazengia, T. Amede, and A. Stroud. 2007. Participatory integrated watershed management: Evolution of concepts and methods in an ecoregional program of the eastern African highlands. Agric. Syst. 94:189-204.
Gichuki, F. 2004. Managing the externalities of dry season river flow: A case study from the Ewaso Ngiro North River Basin, Kenya. Water Resources Res. 40(8).
Gottret, M.A.V.N., and D. White. 2001. Assessing the impact of integrated natural resource management: Challenges and experience. Conserv. Ecol. 5(2):17.
Gouse, M., J.F. Kirsten, B. Shankar, and C. Thirtle. 2005. Bt cotton in KwaZulu Natal: Technology triumph but institutional failure: Technology triumph but institutional failure. Available at http://www.grain.org/research_files/Gouse_etal.pdf. GRAIN, Barcelona.
Gouse, M., L.F. Kirsten, and L. Jenkins. 2003. Bt cotton in South Africa: Adoption and the impact on farm incomes amongst small-scale and large-scale farmers. Agrekon 42:15-28.
Gouse, M., J. Piesse, and C. Thirtle. 2006. Output and labour effects of GM maize and minimum tillage in a communal area of KwaZulu Natal. J. Dev. Perspect. 2:192-207.
Graffham, A. 2006. European standards affect African growers. Pesticide Newsl. 71:14. Available at http://www.pan-uk.org/Projects/Fairness/PN71/pn71p14.pdf.
GRAIN. 1990. Building on farmers' knowledge. Available at http://www.grain.org/seedling/?id=350. GRAIN, Barcelona.
Grey, D. 2004. The World Bank and water resources: Management and development. Water week 2004. World Bank, Washington DC.
Gupta, S., and Y. Yang. 2006. Unblocking trade. Finance Dev. 43(4). Available at http://www.imf.org/external/pubs/ft/fandd/2006/12/gupta.htm
Gyasi, E.A., G. Kranjac-Berisavljevic, E.T. Blay, and W. Oduro (ed) 2004. Managing agrodiversity the traditional way: Lessons from West Africa in sustainable use of biodiversity and related natural resources. Available at http://www.unu.edu/unupress/sample-chapters/Agrodiversity.pdf. UN Univ. Press, Tokyo.
Haile A., D.G. Selassie, B. Zereyacob, and B. Abraham. 2003. On-farm storage studies in Eritrea. DCG Rep. 28. Drylands Coordination Group, Norway.
Hamilton, P., M. Jensen, and R. Southwood. 2004. African Internet country market profiles. Available at http://www.balancingact-africa.com/profile1.html; http://www.balancingact-africa.com/profile2.html; http://www.balancingact-africa.com/profile3.html. Balancing Act News Updates, London.
Hare, P.D., and N.H. Chau. 2002. Excision of selectable marker genes from transgenic plants. Nat. Biotech. 20:575-580.
Harvey, C.A., C. Villanueva, J. Villacís, M. Chacón, D. Muñoz, M. López et al. 2005. Contribution of live fences to the ecological integrity of agricultural landscapes. Agric. Ecosyst. Environ. 111:200-230.
Harwood, R.R., and A.H. Kassam (ed) 2003. Examples of research problems, approaches and partnerships in action in the CGIAR: Research towards integrated natural resources management. Interim Sci. Council, CGIAR, FAO, Rome.
Hauser, S., C. Nolte, and R.J. Carsky. 2006. What role can planted fallows play in the humid and sub-humid zone of West and Central Africa? Nutr. Cycl. Agroecosyst. 76:297-318.
Henao, J., and C. Baanante. 2006. Agricultural production and soil nutrient mining in Africa: Implication for resource conservation and policy development. IFDC, Muscle Shoals AL.
Hobart, F. 2004. The role of market standards and competitiveness in biodiversity conservation. Chemonics, Washington DC.
Hofs, J.L., M. Fox, M. Gouse, and J. Kirsten. 2006. Diffusion du coton genetiquement modifie en Afrique du Sud: Des lecons pour Lafrique zone franc. (In French). Revue Tiers Monde. 188:799-823.
Holmberg, J. 2007. Natural resources in sub-Saharan Africa: Assets and vulnerabilities. Available at http://www.sweden.gov.se/sb/d/9037/a/83507. Rethinking Africa, Gov. Sweden, Stockholm.
Holmgren, P., E.J. Masakha, and H. Sjöholm. 1994. Not all African land is being degraded: A recent survey of trees on farms in Kenya reveals increasing forest resources. Ambio 23:390-395.
Hudson, D.A., and R.G. Jones. 2002. Simulating present-day and future climates of southern Africa using the Hadley Centre regional climate model. Tech. Note, Hadley Centre Climate Predict. Res., Met Office, Bracknell, UK.
IAC (InterAcademy Council). 2004. Realizing the promise and potential of African agriculture: Science and technology strategies for improving agricultural productivity in Africa. IAC, Amsterdam.
ICSTD. 2005. GMO labeling continues to divide CODEX. Bridges Biotech. News 5. UNESCAP, Bangkok.
IFPRI. 2001. Thinking through globalization. Perspective 23. IFPRI, Washington DC.
IPCC. 2007. Summary for policymakers. Climate change 2007: Impacts, adaptation and vulnerability: Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge Univ. Press, UK.
IRIN. 2006. Pastoralist communities in Turkana face rising HIV rate. Available at http://www.aegis.com/news/irin/2006/IR061014.html. Integrated Regional Information Network, Geneva.
Irz, X., L. Lin, C. Thirtle, and S. Wiggins. 2001. Agricultural productivity growth and poverty alleviation. Dev. Policy Rev. 19:449-466.
Itano, N. 2005. Africa's cell phone boom creates a base for low-cost banking. Available at http://www.usatoday.com/tech/products/gear/2005-08-28-cell-banks-africa_x.htm. Christian Science Monitor.
ITU. 2004. Has Africa's ICT renaissance begun? Available at http://www.itu.int/AFRICA2004/media/renaissance.html. International Telecommunication Union, Switzerland.
Izac. A.-M., and P.A. Sanchez. 1998. Toward a natural resource management paradigm for international agriculture: Example of agroforestry research. ICRAF, Nairobi.
Jackson, L.E., U. Pascual, and T. Hodgkin. 2007. Utilizing and conserving agrobiodiversity in agricultural landscapes. Agric. Ecosyst. Environ. 121:196-210.
Jaffe, G. 2006. Comparative analysis of the national biosafety regulatory systems in East Africa: Biotechnology in Africa's development. EPTD Disc. Pap. 146. IFPRI, Washington DC.
James, C. 2007. Global status of commercialized biotech/GM crops. Brief No. 35-2006. ISAAA, Ithaca NY.
Jayne, T., M. Villarreal, P. Pingali, and G. Hemrich. 2004. Interactions between the agricultural sector and the HIV/AIDS pandemic: Implications for agriculture policy. ESA Working Pap. 04-06. FAO, Rome.

Johnson, B. 2000. Genetically modified crops and other organisms: Implications for agricultural sustainability and biodiversity. *In* G.J. Persley and M.M. Lantin (ed) Agricultural biotechnology and the poor. CGIAR, Washington DC.

Kante, S. 2001. Gestion de la fertilite des sols par classe d'exploitation au Mali Sud. (In French). PhD thesis. Wageningen Univ., Netherlands.

Kandji, S.T., L. Verchot, and J. Mackensen. 2006. Climate change and variability in the Sahel region: Impacts and adaptation strategies in the agricultural sector. World Agroforestry Centre and UNEP, Nairobi.

Kenya Ministry of Agriculture. 2004. Strategy for revitalizing agriculture (2004-2014). Available at http://www.kilimo.go.ke/index.php?option=com_content&task=view&id=15&Itemid=99999999. Gov. Kenya, Nairobi.

Kindt, R., A.J. Simons, and P. van Damme. 2004. Do farm characteristics explain differences in tree species diversity among western Kenyan farms? Agrofor. Syst. 63:63-74.

Kiszewski, A., and A. Teklehaimanot. 2004. A review of the clinical and epidemiological burdens of epidemic malaria. Am. J. Trop. Med. Hyg. 71:128-135.

Kumwenda, J.D.T., S. Waddington, S.S. Snapp, J.B. Jones, and M.J. Blackie.1997. Soil fertility management in the smallholder maize based cropping systems of eastern and southern Africa. p. 153-172. *In* C. Eisher (ed) The emerging maize revolution. Michigan State Univ., E. Lansing.

Lakew, K., and Y. Mekonnen. 1998. The health status of northern Omo State farm workers exposed to chloropyrifos and profenifol. Ethiop. Med. J. 36:175-184.

Lal, R. 1999. Integrated watershed management in the global ecosystem. CRC Press, Boca Raton FL.

Leakey, R.R.B., and A.C. Newton.1994. Tropical trees: The potential for domestication and Rebuilding of Forest Resources. HMSO, London.

Leakey, R.R.B., Z. Tchoundjeu, K. Schreckenberg, S.E. Shackleton, and C.M. Shackleton. 2005. Agroforestry tree products (AFTPS): Targeting poverty reduction and enhanced livelihoods. Int. J. Agric. Sustain. 3:1-23.

Lemons, J., R. Victor, and D. Schaffer (ed) 2003. Conserving biodiversity in arid regions: Best practices in developing nations. Kluwer Acad. Publ., Hingham MA.

Lengkeek, A.G., H. Jaenicke, and I.K. Dawson. 2005. Genetic bottlenecks in agroforestry systems: Results of tree nursery surveys in East Africa. Agrofor. Syst. 63:149-155.

Leshner, A.I. 2007. Outreach training needed. Editorial. Science 315:161.

Levey, L.A., and S.J. Young (ed) 2002. Rowing upstream: Snapshots of pioneers of the information age in Africa. Sharp Media, Johannesburg.

Lilles, J.P.B., L.P. Dhakal, P.K. Jha, and H.L. Aryal. 2001. Addressing small holders demand for propagation material of woody species part I: Analysis and strategy proposal. HMG/Danida Seed Centre, Humlebaek.

Liniger, H.P., D.B. Thomas, and H. Hurni. 1998. WOCAT—World overview of conservation approaches and technologies—preliminary result from eastern and southern Africa. p. 1037-1046. *In* Towards sustainable land use. Vol. II. Adv. Geoecology 31. Catena Verlag, Germany

Liniger, H., and W. Critchley (ed) 2007. Where the land is greener: Case studies and analysis of soil and water conservation initiatives worldwide. WOCAT, CTA, Wageningen, FAO, Rome, UNEP, Nairobi and CDE, Berne.

MA. 2005. Ecosystems and human well-being. Vol 1. Current state and trends. R. Hassan et al. (ed) Millennium Ecosystem Assessment. Island Press, Washington DC.

Mafongoya, P.L., A. Bationo, J. Kihara, and B.S. Waswa. 2006a. Appropriate technologies to replenish soil fertility in southern Africa. Nutr. Cycl. Agroecosyst. 76:137-151.

Mafongoya, P.L., E. Kuntashula and G. Sileshi. 2006b. Managing soil fertility and nutrient cycles through fertilizer trees in southern Africa. p. 273-289. *In* N. Uphoff et al. (ed) Biological approaches to sustainable soil systems. CRC Press, Boca Raton FL.

Makumba, W., B. Janssen, O. Oenema, F.K. Akinnifesi, D.Mweta, and F. Kwesiga. 2006. The long term effects of a gliricidia-maize intercropping system in Southern Malawi on gliricidan and maize yields, and soil properties. Agric. Ecosyst. Environ. 116:85-92.

Malakooti, M.A., K. Biomndo, and G.D. Shanks. 1998. Reemergence of epidemic malaria in highlands of western Kenya. Emerg. Infect. Dis. 4:671-676.

Malaney, P., A. Spielman, and J. Sachs. 2004. The malaria gap. Am. J. Trop. Med. Hyg. 71:141-146.

McNeely, J.A., and S.J. Scherr. 2003. Ecoagriculture: Strategies to feed the world and save wild biodiversity. Island Press, Washington DC.

Meinzen-Dick, R., A. Knox, B. Swallow, and F. Place. 2002. Innovation in natural resource management: The role of property rights and collective action in developing countries. IFPRI, Washington DC.

Mekonnen, Y., and T. Agonafir. 2002. Pesticide sprayers' knowledge, attitude and practice of pesticide use on agricultural farms of Ethiopia. Occup. Med. 52:311-315.

Mellor, J.W., and C. Ranade. 2002. Why does agricultural growth in low and middle income countries reduce poverty so much more than urban tradable growth? Abt Assoc., Bethesda.

Mesko, N., E. Wiegers, V. Hermanrud. 2003. Impacts of HIV/AIDS on agriculture in Namibia, Uganda and Zambia. FAO/World Agric. Inform. Center, Rome.

Metcalfe, D., J.D. Astwood, R. Townsend, H.A. Sampson, S.L. Taylor, and R.L. Fuchs. 1996. Assessment of the allergenic potential of foods derived from genetically engineered crop plants. Crit. Rev. Food Sci. Nutr. 36:S165-S186.

Michon, G., and H. de Foresta. 1999. Agroforests: Incorporating a forest vision in agroforestry. L.E. Buck et al. (ed) Agroforestry in sustainable agricultural systems. CRC Press and Lewis Publ., New York.

Minot, N., and M. Ngigi. 2004. Are horticultural exports a replicable success story? Evidence from Kenya and Côte d'Ivoire. Available at http://www.ifpri.org/divs/mtid/dp/mtidp73.htm. IFPRI, Washington DC.

Mistry, P. 1995. Open regionalism: Stepping stone or milestone towards an improved multilateral trading system? p. 3-22. *In* J.J. Teunissen (ed) Regionalism and the global economy. FONDAD, The Hague.

Neondo, H. 2002. More Kenyans consume raw milk due to poverty. Available at http://www.cityfarmer.org/milkKenya.html Urban Agric. Notes, Canada's Off. Urban Agric.

NEPAD (New Partnership for Africa's Development). 2002. Comprehensive African agriculture development programme. NEPAD Secretariat, South Africa.

Ngowi, A.V., D.N. Maeda, C. Wesseling, T.J. Partanen, M.P. Sanga, and G. Mbise. 2001. Pesticide-handling practices in agriculture in Tanzania. Int. J. Occup. Environ. Health 7:326-32.

Nordlee, J.A., S.L. Taylor, J.A. Townsend, L.A. Thomas, and R.K. Bush. 1996. Identification of Brazil nut allergen in transgenic soybeans. New Eng. J. Med. 334:688-692.

Norse, D., and J. B. Tschirley. 2000. Links between science and policy making. Agric. Ecosyst. Environ. 82:15-26.

OAU. 1980. The Lagos plan of action for the economic development of Africa: 1980-2000. Available at http://www.uneca.org/itca/ariportal/docs/lagos_plan.pdf. Org. African Unity, Addis Ababa.

Obuobie, E., B. Keraita, G. Danso, P. Amoah, O.O. Cofie, L. Raschid-Sally et al. 2006. Irrigated urban vegetable production in Ghana: Characteristics, benefits and risks. Available at http://www.cityfarmer.org/GhanaIrrigateVegis.html. IWMI-RUAF-IDRC-CPWF, Accra.

OECD. 2006. Guiding principles on using infrastructure to reduce poverty. Report prepared by the Task Team on Infrastructure for poverty reduction. OECD, Paris.

Okwach, G.E. 2000. Tillage and cover effects on runoff, erosion and soil characteristics in semi-arid Machakos District of Kenya. p. 114-130. *In* E.K. Biamah (ed) Conservation tillage for dryland farming. Technological options and experiences in Eastern and Southern Africa. Workshop Rep. 3, RELMA, Nairobi.

Okalebo, J.R., C.O. Othieno, P.L. Woomer, N.K. Karanja, and J.R.M. Semoka. 2006. Nutr. Cycl. Agroecosyst. 76:153-170.

Omamo, S.W., and J.K. Lynam. 2003. Agricultural science and technology policy in Africa. Res. Policy 32(9):1681-1694.

Onken, A.B., and C.W. Wendt. 1989. Soil fertility management and water relationships. *In* Soil, crop and water management systems for rainfed agriculture in the Sudano-Sahelian zone. Proc. Int. Workshop, Naimey, 7-11 Jan 1987. ICRISAT Sahelian Center, Niamey.

Orden, D., H. Lofgren, and E. Gabre-Madhin. 2004. Trading up: How international trade and efficient domestic markets can contribute to African development. 2020 Afr. Conf. Brief 5. IFPRI, Washington DC.

Oweis, T., and A. Hachum. 2001. Reducing peak supplemental irrigation demand by extending sowing dates. Agric. Water Manage. 50:109-123.

Paarlberg, R., D. Wafula, I. Minde, and J.W. Wakhungu. 2006. Commercial export risks from approval of genetically modified (gm) crops in the COMESA/ASARECA Region. Available at http://www.acts.or.ke/pubs/monographs/pubs/rabesa_report4.pdf. ACTS, Nairobi.

Palm, C.A., S.A. Vosti, P.A.. Sanchez, and P. Ericksen. 2005. Slash-and-burn agriculture: The search for alternatives. Columbia Univ. Press, New York.

Pardey, P. G., N.M. Beintema, S. Dehmer, and S. Wood. 2006. Agricultural research: A growing global divide? Food Policy Rep. IFPRI, Washington DC.

Persley, G. 2003. New genetics, food and agriculture: Scientific discoveries, societal dilemmas. Int. Council Sci., Paris.

Place, F. 1995. The role of land and tree tenure on the adoption of agroforestry technologies in Uganda, Burundi, Zambia, and Malawi: A summary and synthesis. Land Tenure Center, Univ. Wisconsin, Madison.

Place, F., and K. Otsuka. 2000. Population pressure, land tenure, and tree resource management in Uganda. Land Econ. 76:233-251.

Place, F., J. Ssenteza, and K. Otsuka. 2001. Customary and private land management in Uganda. K. Otsuka and F. Place (ed) Land tenure and natural resource management: A comparative study of agrarian communities in Asia and Africa. Johns Hopkins Press, Baltimore.

Place, F., S. Franzel, Q. Noordin, and B. Jama. 2004. Improved fallows in Kenya: History, farmer practice and impacts. EPDT Disc. Pap. IFPRI, Washington DC.

Platteau, J.P. 1996. Physical infrastructure as a constraint on agricultural growth: The case of sub-Saharan Africa. Oxford Dev. Studies 24:189-219.

Polgreen, L. 2007. In Niger, trees and crops turn back the desert. Available at http://rightsandresources.org/blog/Polgreen.pdf. NY Times 11 Feb.

Richards, G., and C. Kirkpatrick. 1999. Reorienting inter-regional cooperation in the global political economy: The Asia-Europe meeting and beyond. J. Comm. Market Studies 37:653-710.

Robinson, E., and F. Tadiar. 1996. Legal, ethical and regulatory aspects of introducing emergency contraceptives in the Philippines. Int. Fam. Plan. Perspect. 22:76-80.

Robbins, P., and R.S.B. Ferris. 2003. The impact of globalization on the agricultural sectors of East and Central African countries. IITA, Manila.

Rockström, J. 2001. Green water security for the food makers of tomorrow: Windows of opportunity in drought-prone savannahs. Water Sci. Tech. 43(4):71-78.

Rockström, J., M. Lannerstad, and M. Falkenmark. 2007. Assessing the water challenge of a new green revolution in developing countries. PNAS 104:6253-6260.

Rosegrant, M.W., M.S. Paisner, S. Meijer, and J. Witcover. 2001. Global food projections to 2020: Emerging trends and alternative futures. IFPRI, Washington DC.

Rozner, S. 2006. Rural leasing. RAFI Note 11. Available at http://www.microlinks.org/ev_en.php?ID=14604_201&ID2=DO_TOPIC. USAID, Washington DC.

Runge, C.F., and B. Ryan. 2004. The economic status and development of plant biotechnology in 2003: Adoption, research and development in the United States. Dept. Appl. Econ. Univ. Minnesota, Minneapolis.

SADC. 2007. Communique of the Meeting of SADC Ministers of Employment and Labour and Social Partners Held in Lusaka, Zambia on 8-9 Feb 2007. Available at http://www.sadc.int/news/news_details.php?news_id=887. Southern Africa Dev. Community, Gaborone.

Sanchez, P.A., and M.S. Swaminathan. 2005. Hunger in Africa: The link between unhealthy people and unhealthy soils. Lancet 365:442-444.

Sayer, J., C.S. Harcourt, and N.M. Collins. 1992. Conservation atlas of tropical forests: Africa. MacMillan Publ., London.

Scherr, S. J. 1999. Soil degradation: A threat to developing country food security by 2020? FAE Discus. Pap. 27. IFPRI, Washington DC.

Schreckenberg, K., A. Degrande, C. Mbosso, Z. Boli Baboulé, C. Boyd, L. Enyong et al. 2002. The social and economic importance of Dacryodes edulis (G.Don) H.J. Lam in southern Cameroon. For. Trees Livelihoods 12:15-40.

Scoones, I. 1998. Sustainable rural livelihoods: A framework for analysis. Inst. Dev. Studies Work.Pap. 72. IDS, Brighton.

Shankar, B., and C. Thirtle. 2005. Pesticide productivity and transgenic cotton technology: The South African smallholder case. J. Agric. Econ. 56:97-116.

Sharer, R. 2001. An agenda for trade, investment, and regional integration. Finance Dev. 38(4).

Shepherd, G., and D. Brown. 1998. Linking international priority-setting to local institutional management. p. 77-87. S. Doolan (ed) African rainforests and the conservation of biodiversity. Earthwatch, Oxford.

Shepherd, K., and F. Place. 2006. Building Africa's capacity in soil science and technology. World Agroforestry Centre, Nairobi.

Simons A.J., H. Jaenicke, Z. Tchoundjeu, I. Dawson, R. Kindt, Z. Oginosako et al. 2000. The future of trees is on farm: Tree domestication in Africa. p. 752-760. Forests and society: The role of research. XXI IUFRO World Congress, Kuala Lumpur.

Simons, A.J., and R.B. Leakey. 2004. Tree domestication in tropical agroforestry. Agrofor. Syst. 61:167-181.

Skutsch, J., and D. Evans. 1999. Realizing the value of irrigation system maintenance. Issues Pap. 2. IPTRID, FAO, Rome.

Smestad, B.T., H. Tiessen, and R.J. Buresh. 2002. Short fallows of *Tithonia diverifolia* and *Crotalaria grahamiana* for soil fertility improvements in western Kenya. Agrofor. Syst. 55:181-194.

Steen, C., R. Magnani, and L. Goldmark. 2005. Competitive strategies for agriculture-related MSEs: From seeds to supermarket shelves. Dev. Alternatives, Washington DC.

Summers, L. 1991. Regionalism and the world trading system. *In* Policy implication of trade and currency zones: A symposium. Federal Reserve Bank, Kansas City.

Tabo, R., A. Bationo, K.D. Maimouna, O. Hassane, and S. Koala. 2005. Fertilizer micro-dosing for the prosperity of small-scale farmers in the Sahel. ICRISAT, Niamey.

Tabor, J.A. 1995. Improving crop yields in the Sahel by means of water-harvesting. J. Arid Environ. 30(1):83-106.

Tchoundjeu, Z., E. Asaah, P. Anegbeh, A. Degrande, P. Mbile, C. Facheux et al. 2006. AFTPs: Putting participatory domestication into practice in West and Central Africa. For. Trees Livelihoods 16:53-70.

Teklehaimanot, Z. 2004. Exploiting the potential of indigenous agroforestry trees: *Parkia biglobosa* and *Vitellaria paradoxa* in sub-Saharan Africa. Agrofor. Syst. 61:207-222.

Thirtle, C., L. Beyers, Y. Ismaël, and J. Piesse. 2003. Can GM-technologies help the poor? The impact of Bt Cotton in the Makhatini

Flats of KwaZulu-Natal. World Dev. 31:717-732.
Thomas, D.S.G., and C. Twyman. 2005. Equity and justice in climate change adaptation amongst natural resource dependent societies. Global Environ. Change 15:115-124.
Thomas, R. 2003. Revisiting the conceptual framework for INRM developed in Penang and Cali. *In* F. Turkelboom et al. (ed) 2003. Putting INRM into Action: 4th INRM Workshop, Aleppo, Syria. 16-19 Sept 2002. ICARDA, Aleppo.
Thornton, P.K., P.G. Jones, T. Owiyo, R.L. Kruska, M. Herrero, P. Krisjanson et al. 2006. Mapping climate vulnerability and poverty in Africa. Report to DFID. ILRI, Nairobi.
Tiffen, M., M. Mortimore, and F. Gichuki. 1994. More people, less erosion: Environmental recovery in Kenya. John Wiley, UK.
Tilman, D. 1997. Distinguishing between the effects of species diversity and species composition. Oikos 80:185.
Tilman, D., P.B. Reich, J. Knops, D. Wedin, T. Mielke, and C. Lehman. 2002. Diversity and productivity in a long-term grassland experiment. Science 294:843-845.
Torero, M., and M. Chowdhury. 2004. Increasing access to infrastructure for Africa's rural poor. Conf. Assur. Food and Nutr. Secur. Afr. 2020, Kampala, 1-3 April 2004. Available at www.ifpri.org/2020africaconference. IFPRI, Washington DC.
Townsend, R. 1999. Agricultural incentives in sub-Saharan Africa: Policy challenges. World Bank. Washington DC.
Uganda Ministry of Works, Housing and Communications. 2003. Uganda national ICT policy framework 2003. Available at http://www.ucc.co.ug/nationalIctPolicyFramework.doc. Gov. Uganda, Kampala.
Uganda Export Promotion Board. 2005. Uganda: Export performance analysis. Available at http://www.ugandaexportsonline.com/docs/2005%20Export%20Performance%20Statistics.pdfGov. Uganda Export Promotion Board, Kampala.
Uganda Investment. 2005. The storage industry. Available at http://www.ugandainvest.com/storage.pdf. Uganda Investment Authority, Kampala.
UNCST. 2007. Bt cotton trials approved in Uganda. Available at http://www.uncst.go.ug/site/index.php?option=com_content&task=view&id=108&Itemid=4. Uganda Nat. Council Sci. Tech., Kampala.
UNECA. 2005. Assessing regional integration in Africa. ECA Policy Res. Pap. UN Econ. Commiss. Africa, Addis Ababa.
UNESCO. 2003. International year of freshwater. Available at http://www.wateryear2003.org/en/ev.php-URL. Uganda Investment Authority, Kampala.
UNEP. 2002. GEO-3: Past, present and future perspectives. Earthscan, London.
USAID. 2003. Internet communications for agricultural researchers. Available at http://africastories.usaid.gov/search_details.cfm?storyID=16&countryID=4&sectorID=0&yearID=3. USAID, Washington DC.
Vanlauwe, B., and K. Giller. 2006. Popular myths around soil fertility management in sub-Saharan Africa. Agric. Ecosyst. Environ. 116:34-46.
Vodafone. 2005. Africa: The impact of mobile phones. Policy Pap. Ser. 3. Available at http://www.vodafone.com/etc/medialib/attachments/cr_downloads.Par.78351.File.tmp/GPP_SIM_paper_3.pdf. Vodafone, UK.
WHO. 2007. UN decade to roll back malaria. Available at http://www.rbm.who.int/cmc_upload/0/000/015/367/RBMInfosheet_6.htm. WHO, Geneva.
Wolfenbarger, L.L., and P.R. Phifer. 2000. The ecological risks and benefits of genetically engineered plants. Science 290:2088-2093.
Wolson, R. 2005. Towards establishment of a vibrant South African biotechnology industry: Will the recent policy interventions achieve their objective? Int. J. Biotech. 7:147-160.
World Bank. 2003. World development report: Sustainable development in a dynamic world: Transforming institutions, growth, and quality of life. World Bank, Washington DC.
World Bank. 2006. World development report: Equity and development. World Bank and Oxford Univ. Press, Washington DC.
Yeats, A.J. 1998. What can be expected from African regional trade agreements: Some empirical evidence. World Bank, Washington DC.

4

Food Systems and Agricultural Products and Services towards 2050

Coordinating Lead Authors:
Daniel N. Dalohoun (Benin), Carol M. Markwei (Ghana)

Lead Author:
Washington O. Ochola (Kenya)

Key Messages

1. While natural resources and climate factors define the possible farming systems, national and international policies and institutional changes will continue to determine the socioeconomic factors that underscore the actual crop and livestock production systems that will prevail in SSA towards 2050. Projections toward 2050 do not predict a substantial improvement of the current state of SSA agriculture, characterized by land pressure due to rapidly growing population, declining soil fertility, frequent droughts, low yields, pests, plant and animal diseases, post-harvest losses and poor management practices.

2. Developing and sustaining competitive crop and livestock production systems in SSA depends on the competitiveness of agricultural innovation—both individual agricultural innovation systems and agricultural innovation taken as a whole. Developing capacity to exploit market opportunities is a prerequisite for increasing competitiveness and reducing the vulnerability of farm households to natural and economic shocks, both of which are prevalent in sub-Saharan African agriculture. Intensification and diversification, expansion, off-farm and exit from agriculture will be the dominant crop production strategies toward 2050. Elements of institutional improvements for agriculture include credit systems and extension and other services which link production to niche markets and strengthen market institutions, particularly through public-private partnerships. Technological solutions including improved production technologies and product quality will also drive agricultural growth in the region.

3. Forestry and agroforestry systems could potentially have positive outcomes toward development and sustainability goals. In these systems the provision of food, timber, non-timber forest products, fibers and other goods will be sustainable. Changes in governance systems that allow for community participation in the management and use of forest systems will lead to both an increase in forest cover and the multiple environmental and economic services they offer. Land tenure reforms and established systems of payment for ecosystems services (PES) will encourage land ownership and stimulate the development of plantations (both forest and agroforest parklands). The development and adoption of AKST for forest and agroforestry species diversity, productivity, pest and disease management, as well as improved access to AKST, will be important for maximizing the benefits from forest and agroforest parklands in the future.

4. The multiple roles of the fisheries and aquaculture sector will intensify towards 2050. The contribution of the sector to poverty reduction will continue to rely on institutional and conservation frameworks that can guarantee sustainable fisheries diversity, improvement in quality and productivity, fish trade expansion, devolution of integrated management of fisheries resources as well as management of invasive alien species. Per capita consumption of fish for food will remain low at less than 7 kg per year, but population expansion and global price increase will sustain growth in capture and aquaculture fisheries. Although capture fisheries will continue to provide the bulk of fish for food in SSA for many decades, multiple pressures will gradually shift the focus to aquaculture, projected to play an increasing role in food security with a 6% rate of expansion by 2020. Local and regional fish trade in SSA will expand through regional cooperation and appropriate national policies, value adding and better market chains. The management of bio-invasion in SSA will have to overcome current challenges of inadequate public–private partnership engagement, apply traditional and local technical knowledge systems, and increase awareness to the environmental, social and economic costs of producing any given species.

5. The agroecosystems of SSA are diverse and have varying potential for sustainable development goals through benefits from agrobiodiversity, agroecotourism and commoditization of services like carbon sequestration. As the numerous benefits and multiple functions of agroecosystems to society become recognized and compensated, such as environmental services, continuity of social and cultural heritage, etc., agriculture in SSA is projected to become more integrated. Agroecotourism will propel economic development only if it is socially accepted in SSA, which depends on opportunities for local communities. The carbon trade and carbon sequestration services provided by agro-ecosystems are already picking up in SSA and are expected to be instrumental to poverty reduction strategies in the region. As the long-term value of agroecosystems are recognized and valued, new institutional mechanisms will be developed to realize effective markets for environmental goods and services.

6. A sub-Saharan Africa with less poverty, greater food security, and a healthier environment is possible, but will not come about without explicit policy steps in that direction. The costs of not making the necessary investments in sub-Saharan Africa will be tremendous, not only to the region but to the rest of the world. Reversing the tide in sub-Saharan Africa enough to allow for an overall economic sustainability would require an increase in total investments on roads, irrigation, clean water, education, and agricultural research. Crop yields would have to grow at a minimum threshold in order to achieve this. Even more significantly, total gross domestic product (GDP) would have to grow at an annual rate of 8 to 10%.

4.1 The Evolution of SSA Food Systems towards 2050

Projections in this chapter build on past and current trends in SSA food systems and existing projections of agricultural products and services to present an assessment of future agricultural and AKST developments. Both a realistic (evolution of current situation with no major changes) and a pessimistic approach to an assessment of future food systems alternatives would lead to system deficits and greater inefficiencies than reported in literature. Conversely, an optimistic approach equates projected production to projected demands. This presents the assessment with the opportunity to address the challenge of food systems in bridging any gaps in relation to development and sustainability goals. The optimistic approach has been adopted in this chapter to futuristically assess the changing face of agriculture in SSA towards 2050. The overall approach to the assessment dwells on answering the question: "*What drivers including evolutions in food systems will shape the production and provision of agricultural goods and services in order to meet the projected demands towards 2050?*"

4.1.1 Crops and livestock production systems

Climate, land and biodiversity. The climate of sub-Saharan Africa is diverse, and controlled by complex interactions between the oceans, land and atmosphere at local, regional and global scales. On average, Africa is hotter, drier and has less-dependable rainfall than all other regions of the world (ICSU, 2006). Further, considering the high climate dependency at all levels from the individual household to the regional economy, Africa is among the most vulnerable continents to climate change and variability (Fischer et al., 2005; IPCC, 2007). Contemporary sub-Saharan Africa is demonstrably vulnerable to both droughts and floods, with negative impacts on degradation in dry lands and coastal zones. Africa's vulnerability is likely to increase in the future, because the future is likely to be far hotter, and large areas are projected to become drier and even more rainfall-variable than at present (ICSU, 2006). For many regions in Africa, however, the direction of future rainfall trends, as well as the magnitude is debated even to the scale of seasonal rainfall forecasts (ICSU, 2006).

In general, Africa has a harsh and increasingly degraded physical environment which, in addition to climatic variability and marked dry seasons, is characterized by fragile ecosystems and chronically low levels of soil fertility which result in land degradation. Projections remain pessimistic about improvements in land degradations in the absence of appropriate institutional, organizational and technological innovations.

The majority of farming systems in SSA are rainfed and only a small area is irrigated despite the higher yield potentials under irrigation (Rosegrant et al., 2002). Except for soybean, baseline projections to 2025 show no significant changes in the proportions of rainfed and irrigated areas (IAC, 2004). The causes of accelerating biodiversity loss vary between locations and between the major plant and animal groups. Over-harvesting has contributed to declines in fisheries, forest and wildlife (ICSU, 2006; IPCC, 2007). Climate change is projected to be the dominant driver of biodiversity loss by the middle of the 21st century (Von Blottnitz and Curran, 2007). For example, an increase in the loss and degradation of wetlands, mangroves and forests is projected.

An Overview of Some Projected Trends in SSA Crop and Livestock Production

Today, approximately 70% of the SSA population is rural. It is projected that between 2030 and 2050, the agricultural population will decline as a result of the development of other economic sectors (Table 4-1) (Dixon et al., 2001). This has implications for crop and livestock production. The major concern is how to meet the increasing demands of the crop and livestock sectors in an environmentally sustainable way. For the next decades, predictions highlight a reduction in crop yield potentials in most tropical and subtropical regions as a result of climate change and diminishing water resources. With relatively fewer people in the agricultural sector, commercial farming will increase.

It is expected that the information revolution will provide large volumes of technological, market and institutional information to farmers. However, it is unlikely that much of this information will serve the majority of SSA producers without investments in education and training for the rural population. These investments will facilitate the transition to commercial farming. This training will encompass entrepreneurial and technical skills.

4.1.2 Forestry, agroforestry and forestry products

Forests and agroforestry systems and forestry products will continue to fulfill environmental, economic, social, cultural needs as well as important needs for nutrition and health (FAO, 2003). These resources are also projected to continue providing the bulk of energy requirements in the form of

Table 4-1. *Total population and urban percentage on different continents.*

Continent	Total population (millions)			Urban population (%)		
	1950	2007	2030	1950	2007	2030
North America	172	339	405	64	81	87
Latin America & Caribbean	167	572	713	42	78	85
Europe	547	731	707	51	74	80
Oceania	13	34	43	61	73	75
Africa	221	965	1,518	15	41	54
Asia	1,398	4,030	4,931	15	41	55
World	2,535	6,671	8,317	29	50	61

Note: the figures for 2030 correspond to the medium variant of the United Nations projections.

Source: Veron, 2007.

fuel wood and charcoal, and would also serve as an energy source for small and medium scale industries. Forests and agroforestry systems will become even more important for protecting watersheds as climate change effects become pronounced in the sub-region (IPCC, 2007). Forest biodiversity will continue to be important for the nutrition (e.g., bush meat as a source of protein), health (medicinal plants) and livelihoods of people in the sub-region. The economies of SSA countries would also be affected positively, as export of non-timber forest products (e.g., curios, bushmeat and medicinal plants), increases due to increased demand by the large number of sub-Saharan Africans in the diaspora.

There have been various assessments on forests in SSA. The Millennium Ecosystem Assessment (MA) based on the Zambezi Basin case study predicts a continuing decline in forest diversity towards 2050, although the rates of decline vary among scenarios (MA, 2005abc). The main driver for the decline in forest genetic resources is expected to be habitat loss resulting from changes in land use. The causes attributed to future habitat loss include land expansion for agriculture and deforestation.

A projection to 2020 in SSA shows that rates of deforestation in East and West Africa will not change significantly (FAO, 2003). In East Africa the continued deforestation will be associated with population growth, intense land use conflicts and poor economic growth. In West Africa continued deforestation will also be associated with land use conflicts. In both Central and Southern Africa deforestation is expected to occur at a higher rate than now, causing a rapid decline in forests. Deforestation in Central Africa will be caused by increased logging, increased road construction and land use conversion. In Southern Africa land reforms in Zimbabwe and expansion of commercial agriculture in Mozambique and Angola are projected to lead to rapid deforestation (FAO, 2003). In the second Africa Environment Outlook (AEO 2) projections on forest systems towards 2050 were based on forest assessments in Central Africa (UNEP, 2006a). Four scenarios resulted in different outcomes under different policies. Under a *Market Forces* scenario, forests will continue to decline but at a slower rate, due to policies that promote afforestation and sustainable use and management of forests. In the *Policy Reform* scenario, there is also a decline in the rate of loss. This decline however, is due to decreased demand in fuel wood and charcoal. The *Fortress World* scenario predicts high rates of deforestation and degradation of forest lands due to commercial over-exploitation of resources and pressure from the rural poor. However, because of international conventions, some forests remain. In the *Great Transitions* scenario, there is an increase in forest cover and improvement in forest quality. This increase will be brought about by an appreciation of the value of forest resources, improved forest management, sustainable use of forestry and improved livelihoods. There is evidence for both pessimistic and optimistic views concerning forest projections (FAO, 2003; MA, 2005a; UNEP, 2006b).

The move towards democratic decision making, transparency and participation of the populace in governance in countries of SSA will have an impact on the state of forest genetic resources towards 2050. For example, The New African initiative focusing primarily on African ownership and management is setting the agenda for renewal of the state of the continent (NEPAD, 2001). The initiative seeks to determine national and regional priorities and development plans through participatory processes involving the people. Some countries are already having a paradigm shift in the role of the public sector from control to policy formulation and support for community participation in the management of forest resources. National governments are involving communities in the management and sustainable use of forests and their resources. The case of the Communal Areas Management Programme for Indigenous Resources (CAMPFIRE) in Zimbabwe, and the successful management of the Duru-Haitemba and Mgori forests in southern Tanzania are examples of how community involvement in the management of forest resources could result in a win-win situation. East Africa, especially Kenya and Tanzania, have attempted similar efforts to integrate wildlife and livestock management. Involving local communities and ensuring equitable sharing of benefits with communities are essential to sustainable management of protected area (Box 4-1).

The vigorous pursuance of these good practices across SSA would reverse the trend of forest genetic decline and enhance/improve the quality and quantity of forest genetic resources and the services they provide for people.

Forest Productivity

The future of forest productivity in SSA remains uncertain (Kirschbaum, 2004). Sub-Saharan Africa's share of global wood production is projected to decline as value-added processing increases. Global trade in processed goods is projected to increase out to 2050; however, in SSA trade will be limited unless there are enabling policies and capital investments in technology and capacity development (FAO, 2003). Over the next decades South Africa will be the leader in exports of high value wood products because of projected capacity development. If West African economies improve, exports of high value wood products will predominate.

The future of non-wood forest products (NWFPs) is uncertain. Currently NWFP including plants used for food, drink, fodder, fuel and medicine and animals and their products, are important in all sub-regions of SSA for subsistence and income generation, and especially for rural livelihoods. NWFPs have potential value in local (Fondoun and Manga, 2000; Sonne, 2001; Adu-Anning, 2004; Ndam, 2004; Ngono and Ndoye, 2004), national (Russo et al., 1996; Tieguhong, 2003), regional (Ngono and Ndoye, 2004) and international trade (Ndam, 2004; Ndoye and Tieguhong, 2004). The discovery of more NWFPs of international value will improve incomes and livelihoods in the sub-region. Good examples include the Batanai Group in the Rushinga District of Zimbabwe, involved in the commercial extraction of marula oil, and the Mapanja Prunus Harvesters' Union in Cameroon, who harvest and trade in *Prunus africana* on Mount Cameroon. The lack of regulatory frameworks has created an environment in which the informal sector and market forces dominate trade in NFWPs and therefore accurate data and projections on their trade are scarce (FAO, 2003). In the case of East Africa, it is expected that the provision of tax incentives would result in value addition to NWFPs by local communities and the private sector.

Box 4-1. A case study of community forest management in Tanzania

In deploying Guards, villagers felt that the forests were no longer their concern. The fact that Forest Guards could be persuaded to issue permits—legally or illegally—to clear fields in the forests, burn charcoal, fell timber, etc., which the elders had not allowed, made their resolve only stronger. In both Duru-Haitemba and Mgori Forests, therefore, large amounts of timber began to be illegally extracted, game hunting multiplied to unsustainable levels, including poaching of elephants for ivory and encroachments by a steady stream of pioneer farmers from neighbouring areas increased. By eliminating the local sense of proprietorship, no matter how weakly this was backed up in statutory law, or implemented on the ground, government also eliminated local guardianship, or recognition in the wider community that the forests were not public property in the "free rider" sense. Indeed, there was a sometimes actively antagonistic mode, both local people and outsiders regarding the forest as for the taking, and government as "fair game". Even those who were dismayed at the degradation taking place (and in Duru-Haitemba concerns that forest degradation was affecting stream flow from the ridges, emerged after 2-3 years) made no attempt to help government foresters identify illegal users among themselves or the more commercial offenders from usually more distant areas.

To ensure sustainable exploitation and management of these two forests, villagers offered the way forward. Village leaders (initially the Duru-Haitemba villages) insisted that they could be active and responsible forest managers by evicting encroachers and banning damaging users. With its hands and budget tied, local government (the Babati District Council) agreed to let them try. The only condition was that Duru-Haitemba remain as uncultivated forest and used only in sustainable ways. Later, in the case of Mgori Forest, which has more income-generating potential, a caveat was added that should commercial utilization take place, the government would receive a share through taxation on forest products sold in the official markets.

The Forest Guards were withdrawn, and the village communities provided with facilitation to decide how they would manage the forests themselves. The main sentiment of villagers at this stage was one of mixed amazement, anxiety and determination, aptly expressed in their fear that, "We have a great responsibility. Now we cannot blame Government if our forest disappears. Our children will blame us if we fail". It is of note that without exception each community promptly banned obviously damaging activities, including those which they had so forcefully insisted were "essential forest uses" at the time the forests were to be owned and managed by the government; Government Foresters watched as encroachers were evicted, charcoal production, ring-barking and forest clearing banned, and the mainly non-local loggers "encouraged" to leave the community. An increasingly nuanced range of regulations were devised and implemented through which fuelwood, pole-wood, and other common requirements were able to be sustainably extracted.

Most villages zoned their "Village Forest Reserves", closing off the most valuable or most damaged areas to consumptive use, confining permitted uses, often including grazing, to certain areas or months of the year. With their forest springs now protected against livestock, several villages rehabilitated the environs with tree planting. Finally, forest guarding was actively instituted, involving selected young men in the community, thereafter exempt from providing other work inputs in the village, and "rewarded" with a share of the fine payments levied on offenders. It is logical that the prime incentive for these communities to actively manage forests is their sense of "ownership", and control over the use and future of the resource. In the kind of forest management arrangements that Duru-Haitemba and Mgori represent, all partners may be seen to benefit; government has lost the burden and costs of fielding Forest Guards and management, and the considerable costs of conflict with local populations.

The villagers themselves gain not only prime rights over the resource but dramatically heightened capacities, again that spills into other spheres of village organization and livelihood. Some villages have used the organization of Village Forest Management to tackle grazing and swamp land management. The forests themselves offer visible evidence of gain; un-regulated in-forest settlement or cultivation, charcoal burning and rampant timber harvesting have all largely disappeared. Boundaries are not only stable but in some cases extended, where a community has added to the area under protection, in stark contrast to the demands for reduction of the proposed government-owned forest reserves. Damaging forest use has dramatically declined to an extent that most villages are looking for other ways to reward their Guards.

In the more degraded Duru-Haitemba the return of under storey shrubbery and grasses, and the return of bee swarms to the forest is a welcome sign of improvement. The return of wildlife in Mgori, is similarly observed. Meanwhile, both Duru-Haitemba and Mgori forests enjoy protection not seen prior to, or during their intended gazettement as forest reserves. For the last 30 months, more than 200 young village men patrol and watch over the two forests. This is at no cost to government, with vested interest in its survival and with local accountability that no government regime could sustainably provide. Perhaps it is this feature more than any other that signals the advantages of community-based forest management.

Although the forestry sector alone will not reduce poverty in SSA, forests will continue to be important to achieving development and sustainability goals. It is projected that value addition of forest resources and community involvement in sustainable forest management will improve livelihoods. (FAO, 2003; Anderson et al., 2004; Mickels-Kokwe, 2006).

4.1.3 Bioenergy

There is a growing potential for the expansion of sub-Saharan Africa energy systems including bioenergy to meet both development and environment goals. Promising opportunities and technologies are being developed including biomass cogeneration and bioethanol. In the medium term (up to 2030), sub-Saharan Africa is projected to remain a net importer of agro-energy technologies and products such as bioethanol (IEA, 2005). Developments beyond 2030 towards 2050 are expected to be shaped by agricultural energy production, the interplay between agricultural energy supply and demand as well as the institutional and policy composition towards this period (Smeets and Faaij, 2006). However, these dynamics will also be influenced by supply and demand for agricultural food production and the availability of fertile land and water—both of which will be influenced by climate change. Whatever trends the future of sub-Saharan Africa follows, agricultural energy will remain key to the sustainability of the regions food systems, human well-being, development and environmental goals.

The following questions will be critical for the prospects for bioenergy and comprehensive integration of sustainable agricultural development and the region's energy needs.

- How are biofuels and rural energy for agriculture infrastructure evolving?
- What is the current state of technology and how will it develop?
- What is the tipping point at which biofuels will impact the energy, agriculture, industry and automotive markets?
- What are the expectations and limits to growth in the biofuels industry?
- How will developments in biofuels impact on sustainable development goals and social as well as environmental well-being?
- What is the potential market for crops to produce biofuels? How will this affect the agriculture sector?

Agricultural energy production. Theoretically, sub-Saharan Africa is one of the regions with the highest potentials for bioenergy production (Woods, 2006). This potential is borne from the large areas suitable for cropland and the low productive and inefficient production systems that offer substantial potential for yield improvements (Sebitosi and Pillay, 2005; Smeets et al., 2007; Smeets and Faaij, 2006). However, there will remain many uncertainties related to this potential (Berndes et al., 2003), including:

- Socioeconomic system dynamics in the region that determine land use patterns and crop yields; and
- Agroecosystems degradation and management regimes that affect bioenergy production capacity from crops and agrobiodiversity.

The "World Energy Outlook" (IEA, 2005) paints a picture of how the global energy system is likely to evolve from now to 2050. If sub-Saharan Africa governments stick with current energy policies, the region's energy needs will be almost 60% higher in 2030 than they are now. A similar trajectory will see this trend persisting until 2050. Whether this rising demand for energy can be met and how it will be supplied will depend on government policies and investment patterns. In any event, fossil fuels will continue to dominate the region's energy mix, meeting most of the increase in overall energy use. However, the contribution of agricultural energy production is predicted to increase, although it will continue to be dominated by the polluting and unsustainable combustion of traditional bioenergy, e.g., fuel wood and agricultural residues burned in inefficient cookstoves (Demirbas, 2007). Given the considerable social and environmental costs (including gender inequality, indoor air pollution and deforestation) of traditional bioenergy, the challenge for the next decades will remain the need to increase energy efficiency (improved stoves and charcoal making techniques) and to promote modern energy sources (to enhance agricultural productivity and for rural services such as electricity).

Modern bioenergy will present one option for improving access to modern and efficient energy services but it will be a challenge to exploit existing agroecosystems efficiently and sustainably without unduly disrupting the food systems.

Bioenergy offers considerable potential for an expansion of electricity and heat production, especially in the form of biomass cogeneration (e.g., from sugarcane bagasse). Some sugar-producing countries (e.g., Mauritius) have already expanded their cogeneration capacity and it is very likely that more African countries will follow this path of efficient and low-cost energy production (IEA, 2005; Woods, 2006). Various technologies are also being developed that could increase the attractiveness of bioenergy for the provision of modern energy in small-scale rural applications. Technologies ranging from biogas to unrefined bio-oils could contribute to meeting local energy needs through the integration of energy production with agricultural and forestry activities (see chapter 6, IAASTD Global Report).

With respect to liquid biofuels, it is highly likely that with the removal or easing of barriers to its trade, the biofuel industry—including ethanol and biodiesel produced from crops—will have far-reaching effects on sub-Saharan African agriculture. It is however difficult to foresee the welfare effects this would bring about. On the one hand, novel development opportunities may arise in countries with significant agricultural resources. The region, with its significant sugar cane and sweet sorghum production suitability, could profit from Brazil's experience and technology (FAO, 2006a). The scenarios by the Cane Resources Network for Southern Africa (CARENSA) indicate a potential for the production of bioethanol from sugar crops in southern Africa in magnitudes that could meet domestic demands and export markets in the region (Figure 4-1).

On the other hand, the comparatively high costs of sugar production in Africa will pose a significant challenge for ethanol development. Moreover, much of the land on which the above scenarios are based is remotely located or

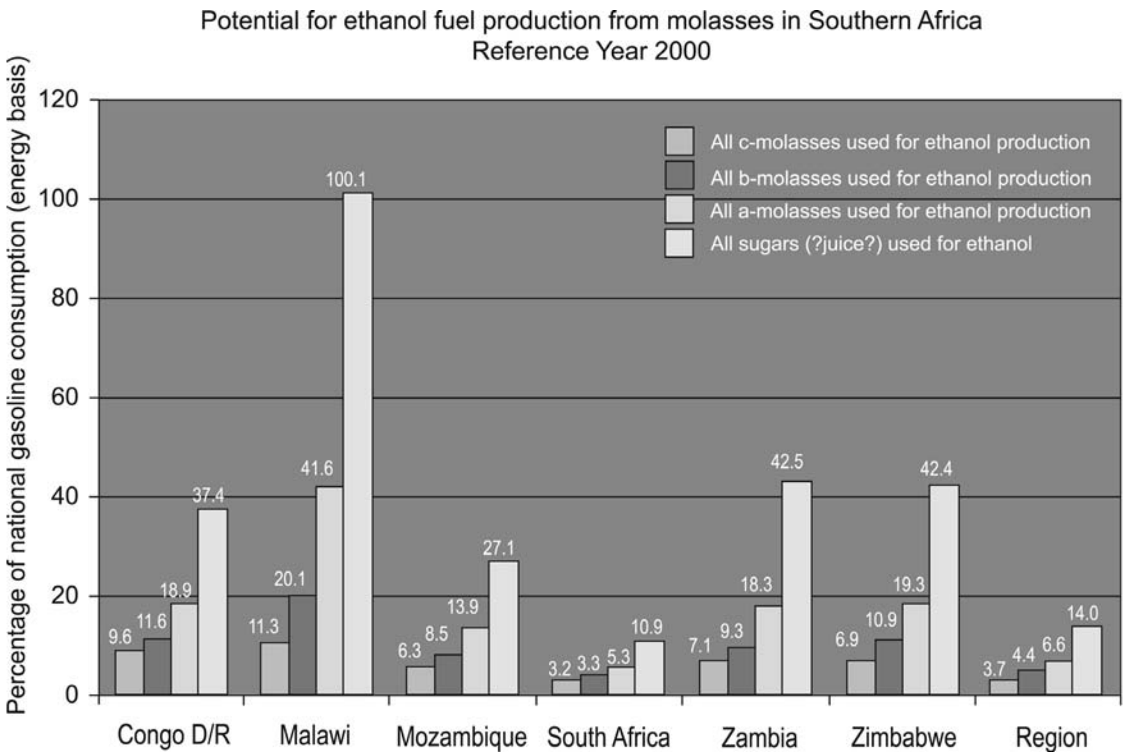


Figure 4-1. *Potential for ethanol fuel production from molasses in southern Africa. Source: Based on CARENSA scenarios, Woods et al., 2005.*

not currently suitable for crop production and would require large investments in irrigation and other infrastructure before it could produce crops. In addition to these economic barriers, a large-scale expansion of agricultural production for biofuels would also encounter environmental limits in the form of water availability and threats to natural vegetation and forests (Berndes et al., 2003). Climate change will also affect these factors in the envisioned timeframe. Finally, increasing the demand for biomass for biofuels production could have considerable impact on food prices—threatening food security for many poor net buyers of food.

Agricultural energy requirements and consumption. It is highly likely that towards 2050 many countries in sub-Saharan Africa will continue to have some of the lowest per capita energy consumption levels in the world. The projected increase in yields and production in agriculture as a result of energy inputs can lead to important social and environmental gains. Agro-industrial growth will in itself increase energy requirements (Smeets et al., 2007). An assessment of the region's future agricultural energy demand and supply is complex due to unique social and political elements as well as concerns for the food security of millions of people. The past and present energy situation in Africa's agricultural sector has been analyzed systematically, showing that agricultural productivity in sub-Saharan Africa will continue to be closely associated with direct and indirect energy inputs, and there will be continued need for policies to consolidate this relationship for the benefit of farmers and agroecosystems in the region (FAO, 2006a). However, for this to materialize there will be a need, unlike in the past decades, to design and implement agricultural development and extension plans that pay due regard to this synergy. The Comprehensive African Agricultural Development Program (CAADP) of the NEPAD is poised to drive the region's agriculture and foods systems toward this goal (NEPAD, 2004).

The future relationship between agriculture and energy will largely be shaped by direct and indirect drivers of changing farming systems and patterns (traditional vs. mechanized vs. irrigated) that will alter energy efficiency and production characteristics. The changes in the agricultural yield that will come with an increase in energy and chemical as well as changes in agricultural and post harvest processing technologies like crop curing, drying and processing will also play part. An IFPRI-sponsored assessment concludes that although many questions remain unresolved, there will continue to be synergy between bioenergy, development and agricultural sustainability in SSA (Hazell and Pachauri, 2006). The IMPACT model (Rosegrant et al., 2002) presents scenarios for biofuels that offer understanding for biofuel growth and productivity specific to SSA. The particular challenge will be reconciling food and fuel demand tradeoffs. In the absence of a solution to this tradeoff, the use of cassava and other agricultural crops as bioenergy feedstock is highly likely to raise agricultural prices leading to sizeable welfare losses—especially for the poorest strata of society.

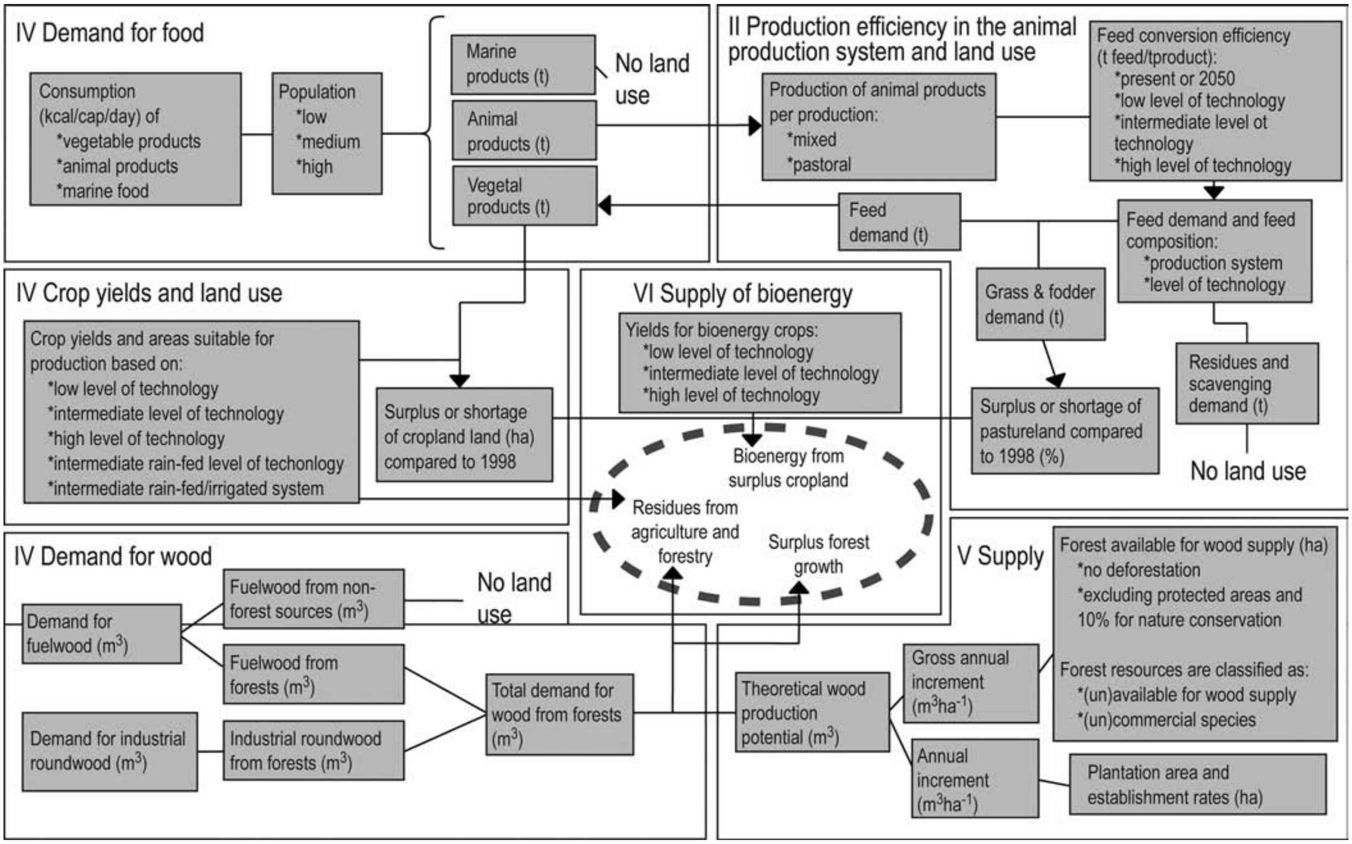


Figure 4-2. *The key elements of the assessment for crop-specific bioenergy needs. Source: Adopted from FAO, 2006a.*

Future trends in organizational arrangements and support. Current baseline trends show that for energy to be produced sustainably in agriculture the following options may be considered:

- Energy options for specific development goals such as food security and agro-industry development;
- Options for the entire "food chain," assessing energy requirements including the critical linkages between agricultural production, agricultural-based industries (food, beverage, tobacco, and textiles), distribution and commercialization, and the rest of the economy;
- Energy production that would allow sub-Saharan Africa to meet the projected two to threefold increase in agricultural energy requirements by 2010 relative to present levels;
- The energy implications of low-input farming techniques such as integrated pest management, low-tillage cultivation, use of residues, green manures, and other organic fertilizers, which are projected to play an important role in sustainable agricultural development in the region;
- Assess the technical feasibility as well as social, environmental, and economic costs and benefits of bioelectricity (e.g., from cogeneration or biogas).

The current weaknesses in institutional links and responsibilities between the various sectors involved in agricultural policy and technology both as energy consumers and producer will have to be overcome through local, national and regional frameworks. These frameworks will also need coordinated planning at local, regional and national levels by up-scaling local needs and enhancing broad-based participation.

Implications of policies on land tenure for biomass conversion to energy, which include property rights of both land and produce—such as biomass from forests—is generally weak in sub-Saharan Africa and their consideration will be key to sustainable bioenergy production and use in agriculture. Future initiatives expected to broaden technologically sound agrobioenergy development in sub-Saharan Africa and contribute to the provision of equitable access to sustainable energy from agriculture and for agriculture will have to as a prerequisite:

- Raise political awareness among high level decision makers of the important role energy can play in poverty reduction;
- Clarify the need for energy services for poverty reduction and sustainable development;
- Assess the tradeoffs between food security and biofuels production at the local, national and region level;
- Make apparent the need for energy services in national/regional development strategies;
- Encourage the coherence and synergy of energy related activities;

- Stimulate new resources (capital, technology, human resources) from the private sector, financial institutions, civil society and end-users;
- Include institutional capacity building, transfer of knowledge and skills, technical cooperation and market development.

Future implications to development and sustainability goals. Although a feasibility study including food and fuel tradeoffs is needed, the emerging opportunities for biofuel production in the region may be an avenue toward economic development in sub-Saharan Africa. The range of new value addition and agricultural activities created in the production, processing, transport and storage of residues and energy dedicated crops will also increase non-farm economic opportunities (Sebitosi and Pillay, 2005). With the accompanying investment in infrastructure and potential opportunities for local ownership of the conversion industry, options for poverty reduction may improve.

Different development pathways are viable in attempting to achieve the various visions for sub-Saharan Africa bioenergy. The future will largely be dictated by the desire to integrate sustainable agriculture concerns, social development objectives and climate and global environmental change objectives with bioenergy expansion (ICSU, 2006). The most productive bioenergy pathways will be those that improve consumption per capita, in addition to improving or maintaining acceptable social and environmental quality. The rural electrification master plans, for instance, will have to target not only households but also the energy needs for agricultural production, factoring in the energy production potential of agroecosystems. Sustainable bioenergy policies should therefore aim for an agriculture and energy interaction that will provide affordable, accessible and reliable energy services that meet economic, social and environmental needs within the overall developmental context of the society in the region.

4.1.4 Fisheries and aquaculture

The fisheries sector will continue to play multiple roles in SSA economies and will be instrumental for achieving food security, poverty reduction and sustainable development (FAO, 2006b) (Table 4-2). Projections indicate that by 2025 over 60% of poor people in SSA will still be rural. This will continue to have significant implications for fisheries as the sector has the potential to contribute to improved livelihoods and food security (Figure 4-3) (Thorpe, 2004; Thorpe et al., 2004; Béné et al., 2006; FAO, 2006c; Isaacs et al., 2005, 2007).

Fisheries diversity. Projected fish species loss for 13 SSA rivers including the Senegal (52% loss) and Okavango (20% loss) are due primarily to climate change and water withdrawals (Xenopoulos et al., 2005; IPCC, 2007). Freshwater taxa are projected to suffer more from land use changes and invasive species than from climate change. In rivers with reduced discharge, up to 75% of local fish biodiversity will be extinct by 2070.

Capture fisheries will continue to provide the bulk of fish food in Africa for many decades. Hence, SSA will experience increasing pressure on capture fish especially in the large fresh water systems such as Lake Victoria (UNEP, 2006b). Aquaculture will play an increasing role in food security in Africa as small-scale integrated systems provide additional employment for growing rural populations (WorldFish Center, 2005). In periurban areas small-scale enterprises will increase to meet urban demands for higher quality fish products.

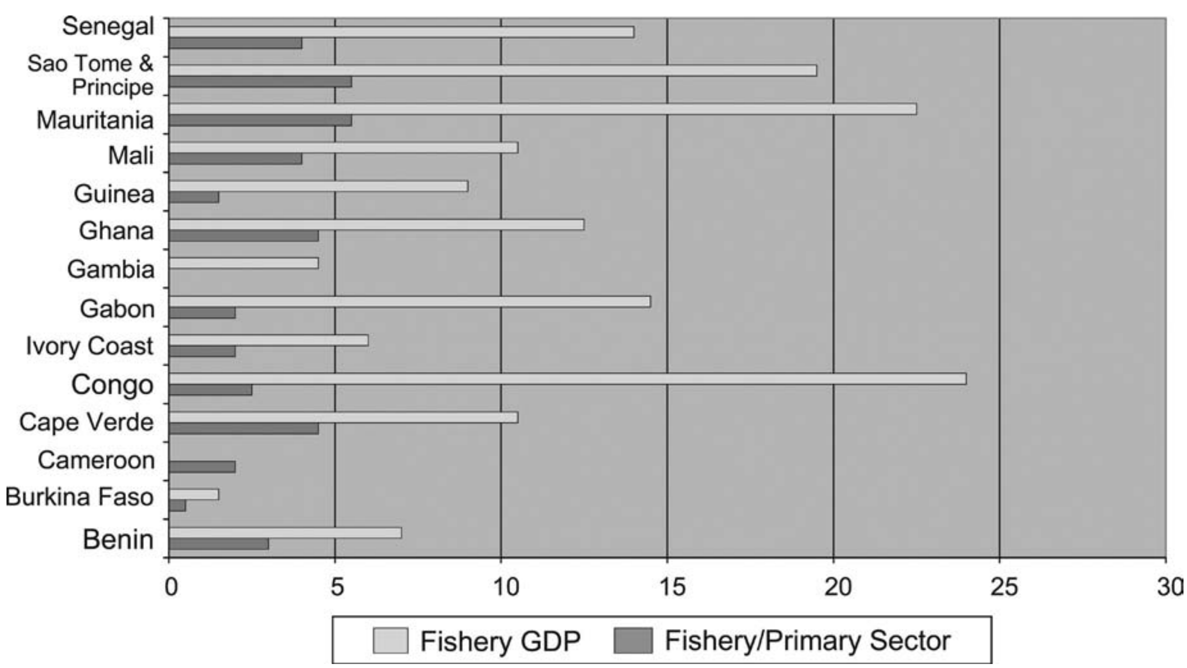


Figure 4-3. *Contribution of fisheries to the GDP of selected West and Central African countries. Source: FAO, 2006b.*

Commercial fish farming systems will be characterized by higher levels of management, capital investment, higher levels of quality control and a more complex and structured market (FAO, 2006cd). These systems will involve different levels of intensification and will be dominated by large scale producers such as Nigeria, South Africa and Madagascar although countries like Côte d'Ivoire, Republic of Congo, Ghana and Kenya will also experience rapid progress. Seaweed and prawn culture is likely to expand in coastal areas and small island states. South Africa and Namibia will lead high value fish farming such as abalone (FAO, 2006c). The region is also likely to see a growth in mussel and oyster culture and an expansion of non-food aquaculture technologies. Cichlids (*Oreochromis* and *Tilapia* spp.) will continue to be most commonly used species, though polyculture with *Clarias gariepinus* and *Cyprinus carpio* will emerge in some countries. It will be important for SSA countries to develop fisheries monitoring and diagnostic tools in order to respond to environmental changes (Neiland et al., 2005).

Local and regional fish trade in SSA has the potential to expand and help stimulate markets at multiple levels. Market expansion at the domestic level will lead to quality and safety measures needed to increase global trade (Delgado et al., 2003). SSA fish producers, processors and marketers will have to increasingly contend with stringent quality requirements and standards set for fish products. The competiveness of fish products from sub-Saharan Africa will remain critical for the survival of the industry (Ponte et al., 2005, 2007). The future of aquaculture and fisheries will also depend on enforcement of eco-labels on marine products (based on FAO guidelines) and certified fish production standards worldwide. The roadmap set by NEPAD (NEPAD, 2005) for fisheries development provide policy guidelines for improvement while local management options exist for ensuring that competitiveness in the world markets is achieved (Raakjaer-Nielsen et al., 2004; Astorkiza et al., 2006; Hegland, 2006; Raakjaer-Nielsen and Hara, 2006; Wilson et al., 2006).

4.2 The Evolution of Agricultural Products and Services toward 2050

4.2.1 Cereals, roots and tubers

Sub-Saharan Africa is projected to have a cereal shortage to 2050. Overall baseline projections to 2020 show an increase in cereal use for animal feed because of increased demand for meat (Rosegrant et al., 2001). By 2020 despite positive growth rates in cereal production (Figure 4-4) and production increases through cultivated land expansion, SSA will not be able to meet cereal demands. High food import levels may be economically and politically unsustainable. If SSA has high population growth and sluggish economic performance, it will likely face food shortages. SSA's projected lack of foreign exchange may weaken their ability to pay for food imports (Rosegrant et al., 2001) (Figures 4-5 and 4-6).

Table 4-2. *2010 projections of sub-Saharan Africa fish production.*

Scenarios	Pessimistic	Optimistic
	Million tonnes	
Capture fisheries	80	105
Aquaculture production	27	39
Total production	107	144
Less fish for nonfood uses	33	30
Available for human consumption	74	114

Source: Rosegrant et al., 2001.

Projections highlight that it is unlikely that sub-Saharan Africa will follow the same path as Asia toward rapid agricultural growth, because SSA faces different constraints, such as higher costs of water exploitation, and limited transportation and communications infrastructure. Future increases in crop production will have to come from more intensive production on existing agricultural land or land expansion (MA, 2005abc). More intensive agricultural production will have to be accompanied by improved natural resources management, substantial investments in agricultural inputs, such as fertilizer and irrigation, and roads, clean water, and education.

Roots and tubers are projected to increase in importance because of their adaptability to marginal environments (IPCC, 2007). Projections of output and consumption patterns for roots and tubers in SSA are based on the end use and show an overall trend toward greater specialization in end use and an increase in the variety of production systems (Scott, et al., 2000). Cassava and sweet potato, for example, will increasingly be used in processed form for food, feed and starch-derived products (Table 4-3 and 4-4). Non-food and non-feed uses will grow in volume as a result of technologies that enhance varietal characteristics and reduce production costs. As urbanization increases, more people will purchase processed food.

4.2.2 Meat, dairy and poultry production

Worldwide, demand for meat is projected to rise by more than 55% (Figure 4-7) between 1997 and 2020, with most of the increase occurring in developing countries (Rosegrant et al., 2001). Baseline projections towards 2020 indicate that poultry will account for 40% of the global increase in demand for meat, far higher than the 28% it accounted for in 1997, reflecting a shift in taste from red meat to chicken (Figure 4-8).To meet the rise in demand for meat, farmers will need to grow more cereals, particularly, maize for animal feed rather than for human uses.

4.2.3 Horticulture and nonfood products

ICT would have to support trade development in the coming decades with information on technologies for handling, processing and marketing (including markets and products) horticultural and nonfood products. High quality products coupled with an investor-friendly environment would boost trade in nonfood products.

Cotton and fiber products. The cotton textile industry in SSA will require creative and innovative management to be competitive. Government's role will be to create an enabling

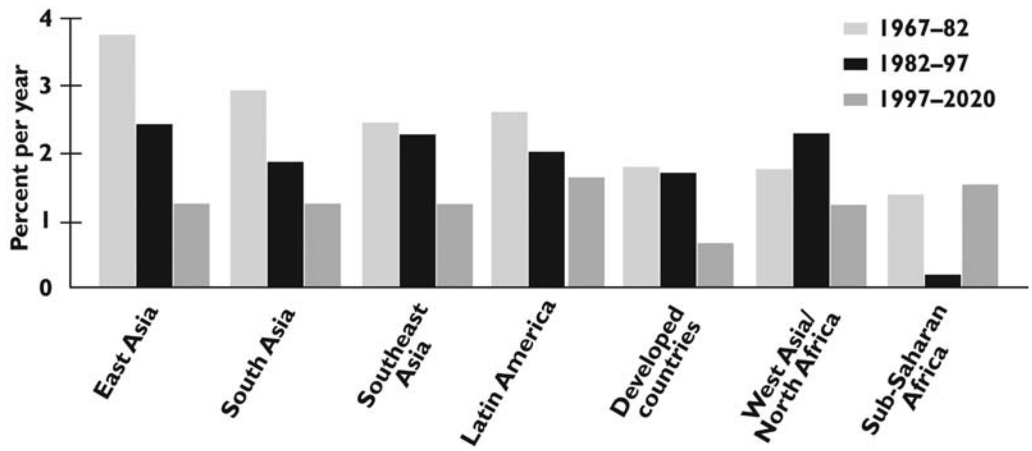


Figure 4-4. *Cereal yield growth rates by region, 1967-2020. Source: Rosegrant et al., 2001 based on IFPRI IMPACT projections and FAOSTAT.*

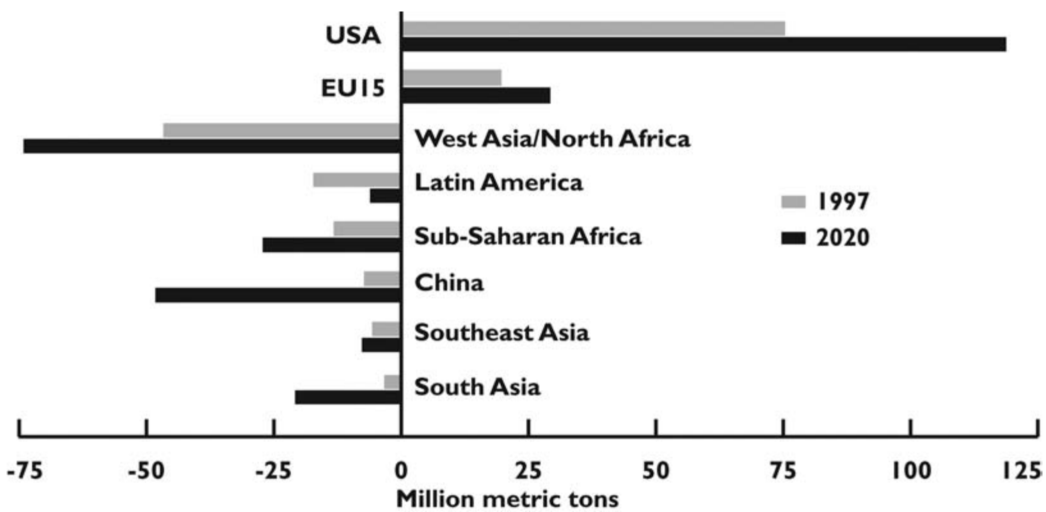


Figure 4-5. *Net trade in cereals by region, 1997 and 2020. Source: Rosegrant et al., 2001 based on IFPRI IMPACT projections.*

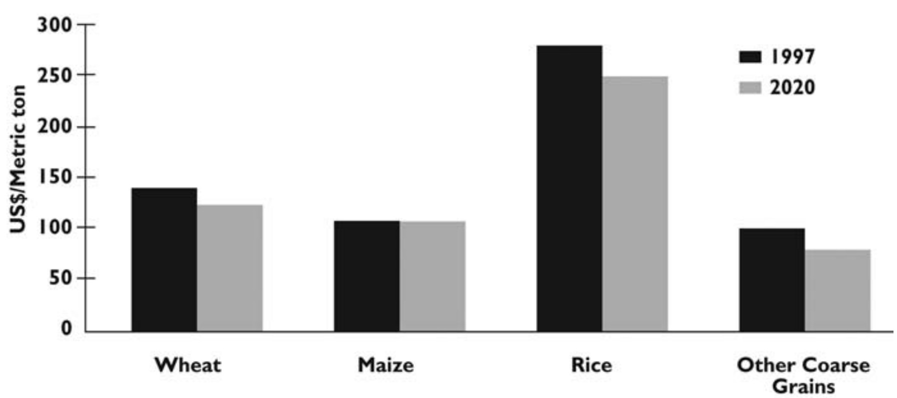


Figure 4-6. *Cereal prices by crop, 1997 and 2020. Source: Rosegrant et al., 2001 based on IFPRI IMPACT projections.*

Table 4-3. *Use of roots and tubers in 1993 and projected to 2020, baseline scenario.*

Region	Cassava		Potato		Sweet potato and yam		All roots and tubers	
	(million tonnes)							
	1993	2020	1993	2020	1993	2020	1993	2020
Sub-Saharan Africa	87.7	168.1	2.8	6.3	36.0	74.5	126.4	248.9
Developing countries	152.0	254.6	95.2	163.2	155.5	217.3	402.7	635.1
Developed countries	20.7	20.5	190.1	206.2	2.5	2.7	213.3	229.4
World	172.7	275.1	285.3	369.4	158.0	220.0	616.0	864.5

Source: IMPACT Simulations; Scott et al., 2000.

Table 4-4. *Projected annual growth rates for roots and tubers, 1993-2020, baseline scenario.*

Region	Cassava			Potato			Sweet potato and yam			All roots and tubers		
	Food	*Feed*	*Fiber*	*Food*	*Feed*	*Fiber*	*Food*	*Feed*	*Fiber*	*Food*	*Feed*	*Fiber*
	(% per year)											
Sub-Saharan Africa	2.49	1.53	2.44	3.10	1.81	3.10	2.74	1.89	2.73	2.55	1.56	2.54
Developing countries	1.99	1.62	1.93	2.33	0.37	2.02	0.44	1.81	1.25	1.62	1.57	1.70
Developed countries	-0.50	0.01	-0.04	0.37	0.22	0.30	0.28	0.61	0.33	0.36	0.15	0.27
World	1.98	0.95	1.74	1.20	0.26	0.96	0.43	1.80	1.23	1.30	1.07	1.26

Source: IMPACT Simulations; Scott et al., 2000.

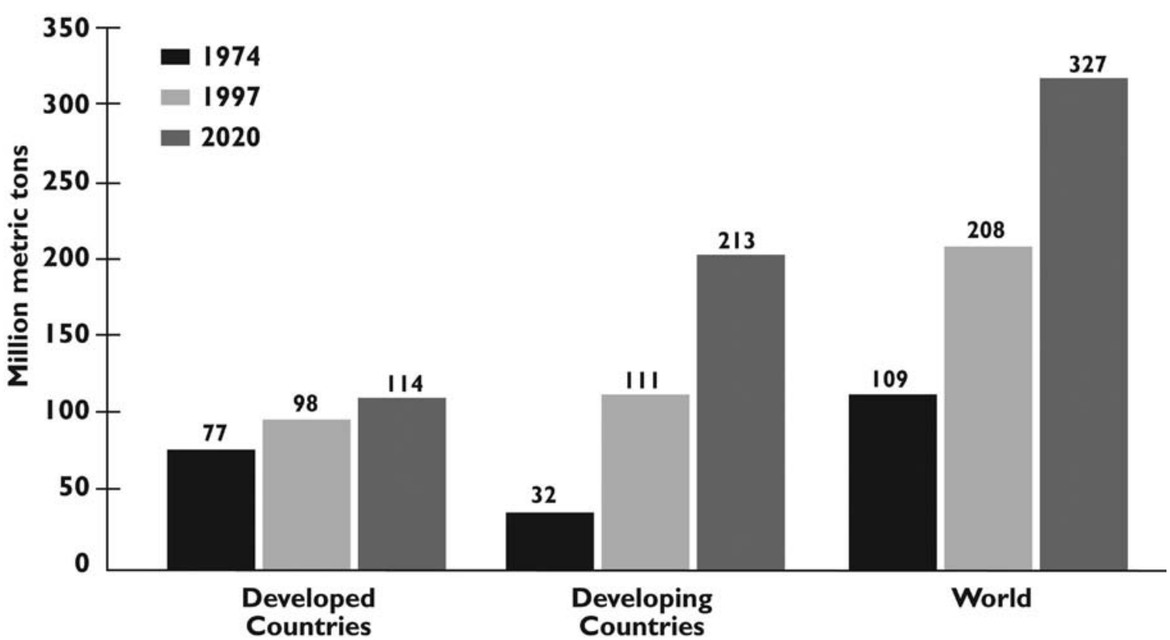


Figure 4-7. *World demand for meat, 1974, 1997, and 2020. Source: Rosegrant et al., 2001 based on IFPRI IMPACT projections.*

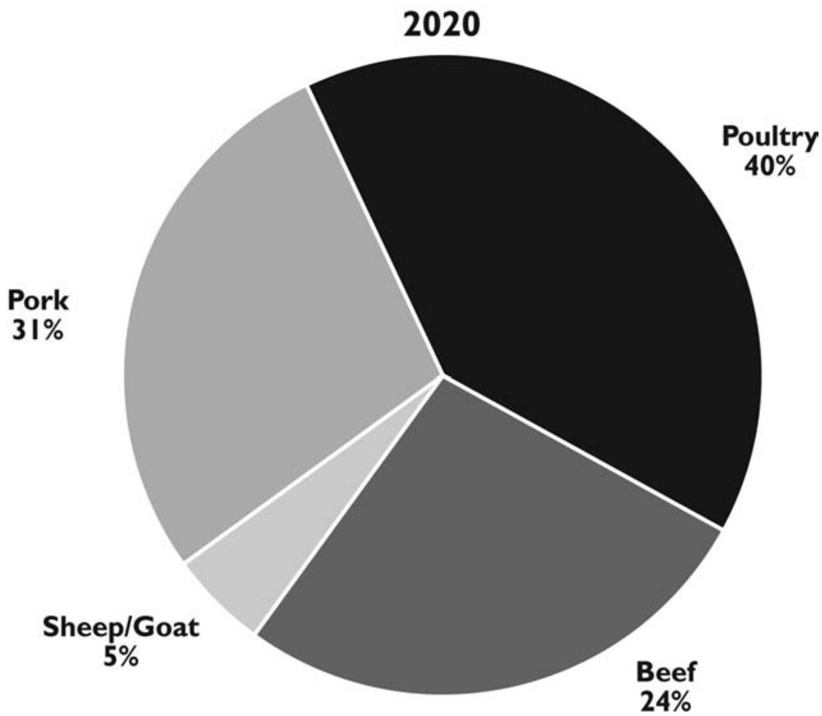


Figure 4-8. *Increase in demand for meat. Increase in demand for meat 1997-2020. Source: Rosegrant et al., 2001 based on IFPRI IMPACT projections.*

environment for the private sector through policies involving taxation and marketing. Mill usage in SSA is projected to create additional jobs and generate income for more people.

Floriculture and horticulture. SSA competitiveness in the floriculture sector will depend on successful marketing and use of ICT, including date information on markets and their sizes, product demand, education and extension on production, processing, and handling. This sector will be increasingly competitive (Table 4-5) (Kane et al., 2004; Minot and Ngigi, 2004; CIAT, 2006). The trade in fresh fruits and vegetables with Europe will depend on the level of consumption and population growth (Table 4-6). Exporters from SSA will also have to meet the changing standards and certification requirements, including in the organic market (Collinson, 2001; NRI, 2002; Smelt and Jager 2002; Jaffee, 2003; Hallam et al., 2004). As eating patterns in the developed world become healthier, (e.g., increased fruit and vegetable consumption), there will continue to be demand for fresh horticultural products year round. A stable economic and political climate will be needed for investor confidence. Infrastructure such as roads, airport facilities, information and communication systems, reliable power and water supply, control, testing and certification services will be required to ensure competitiveness.

Agroecosystem tourism. Tourism and agroecotourism in particular in SSA will remain viable towards 2050. Tourist arrivals are projected to increase at an average annual rate of 7% per year until 2020 (WTO, 2005). Though agroecotourism is believed to propel economic development, its social acceptance in SSA will continue to depend on opportunities presented to local communities. The recognition of agroecotourism's growth potential will have a positive impact on investments in many SSA countries and is poised to contribute to key sustainability and development goals (Giuliani, 2005).

Carbon sequestration and trade. The Kyoto Protocol's Clean Development Mechanism will enable industrialized countries to set up carbon offset projects in SSA. Carbon investments are projected to reduce poverty and protect vulnerable ecosystems. The present carbon trade project in SSA constitutes less than 10% of the international carbon trading. The situation is set to change with the entry of Kyoto compliant projects and numerous voluntary emissions with incentives from the World Bank's BioCarbon Fund (World Bank, 2006).

Payment for ecosystems services. To appreciate the long-term value of environmental services from agroecosystems, new institutional mechanisms will be needed to develop effective markets for ecosystems goods and services. This includes mechanisms for the operationalization of the costs of environmental damage and the benefits of environmental protection into agricultural production and marketing decisions and policy. Such efforts are likely to be most successful in countries where there is a clear, politically expressed perception of environmental scarcity or threat. This will likely happen in areas of population or production pressures, rural and urban poverty, or threatened biodiversity.

Table 4-5. *Cutflower imports into Europe from sub-Saharan Africa, 2002.*

	Value (US$1000)	Share of Total (%)
Kenya	222,664	62
Zimbabwe	72,887	20
Zambia	24,587	7
Uganda	15,008	4
South Africa	12,108	3
Tanzania	9,293	3
Ivory Coast	4,703	1
Total imports	**361,251**	**100**

Source: Integrated Framework, 2005.

Table 4-6. *Sub-Saharan African vegetable exports to the EU, 2003.*

	Volume (tonnes)	Share of total (%)
Kenya	48,183	41.8
South Africa	22,112	19.2
Senegal	8,551	7.4
Zimbabwe	7,810	6.8
Ghana	7,719	6.7
Zambia	7,132	6.2
Uganda	3,189	2.8
Ethiopía	2,840	2.5
Burkina Faso	1,375	1.2
Madagascar	1,179	1.0
Gambia	1,074	0.9
Ivory Coast	1,014	0.9
Tanzania	842	0.7
Others	2,146	1.9
Total	115,166	100.0

Source: Temu and Temu, 2006.

References

ADB. 2007. Selected statistics for African countries 2007. Volume XXVI. African Dev. Bank, Ivory Coast.

Adu-Anning, C., 2004. The rattan industry in Ashanti and Western region of Ghana. p 263-274. *In* T. Sunderland and O. Ndoye (ed) Forest products, livelihoods and conservation. Case studies of non-timber forest product systems: Vol. 2, Africa. CIFOR, Bogor.

Anderson, A., D. Bryceson, B. Campbell, D.Chitundu, J.Clarke, M. Drinkwater, et al. 2004. Chance, change and choice in Africa's drylands: A new perspective on policy priorities in the drylands of Africa. CIFOR Policy Brief. Available at http://www.cifor.cgiar.org/publications/pdf_files/research/livelihood/Dryland.pdf. CIFOR, Bogor.

Astorkiza, K., I. del Valle, I. Astorkiza, T.J. Hegland, and S. Pascoe. 2006. The knowledge base for fisheries management. Dev. Aquacult. Fish. Sci. Ser. 36:9.

Béné, C., G. Macfadyen, and E.H. Allison. 2006. Enhancing the contribution of small-scale fisheries to poverty alleviation and food security. Fish. Tech. Pap. 481. FAO, Rome.

Berndes, G., M. Hoogwijk, and R. Van den Broek. 2003. The contribution of biomass in the future global energy supply: A review of 17 studies. Biomass Bioenergy 25:1-28.

CIAT. 2006. Snap beans for income generation by small farmers in East Africa. CIAT in Africa. Highlights No. 31, June 2006. Available at http://www.ciat.cgiar.org/africa/pdf/highlight31.pdf. CIAT, Cali.

Collinson, C. 2001. The business costs of ethical supply chain management: Kenyan flower industry case study. Nat. Resources Inst., Kent.

Delgado, C., N. Wada, M. Rosegrant, S. Meijer, and M. Ahmed. 2003. Fish to 2020: Supply and demand in changing global markets. IFPRI, Washington DC and WorldFish Center, Penang.

Demirbas, A. 2007. Progress and recent trends in biofuels. Progress Energy Combustion Sci. 33:1-18.

Dixon, J., A. Gulliver, and D. Gibbon. 2001. Farming systems and poverty—Improving farmers' livelihoods in a changing world. FAO, Rome and World Bank, Washington DC.

FAO. 2003. Forestry outlook study for Africa Eur. Commission, African Dev. Bank and FAO, Rome.

FAO. 2006a. Bioenergy option: Introducing the international bioenergy platform. IBEP, FAO, Rome.

FAO. 2006b. Contribution of fisheries to national economies in West and Central Africa: Policies to increase the wealth generated by small-scale fisheries. New Directions Fish. Policy Briefs No. 03. Available at http://www.sflp.org/briefs/eng/notesynthese.html. FAO, Rome.

FAO, 2006c. Regional review on aquaculture development: Sub-Saharan Africa 2005. Fish. CircularNo. 1017/4 FIRI/C1017/4. FAO, Rome.

FAO. 2006d. Assessment of the world food security situation. Committee on World Food Security, Rome. 30 Oct-4 Nov 2006. FAO, Rome.

Fischer, G., M. Shah, N. Tubiello, and H. van Velthuizen. 2005. Socio-economic and climate change impacts on agriculture: An integrated assessment, 1990-2080. Phil. Trans. R. Soc. 360:2067-2083.

Fondoun, J.M., and T. Manga. 2000. Farmers' indigenous practices for conserving *Garcinia kola* and *Gnetum africanum* in southern Cameroon. Agroforest. Syst. 48:289-302.

Giuliani, A. 2005. Agrobiodiversity conservation and agro-ecotourism: Opportunities to improve livelihoods. Int.

Workshop Rural Tourism and Sustainable Development: Promoting a pro-poor approach, Rome, 17-18 Nov 2005. IPGRI, Rome.

Hallam, D., P. Liu, G. Lavers, P. Pilkauskas, G. Rapsomanikis, and J. Claro. 2004. The Market for non-traditional agricultural exports. Commod. Trade Tech. Pap. 3. FAO, Rome.

Hazell, R., and R.K. Pachauri (ed) 2006. Bioenergy and agriculture: Promises and challenges. Focus 14. IFPRI, Washington DC.

Hegland, T.J. 2006. Fisheries policy-making: production and use of knowledge. *In* L. Motos and D.C. Wilson (ed) The knowledge base for fisheries management. Dev. Aquacult. Fish. Sci. Ser. 8:36.

IAC (InterAcademy Council). 2004. Realizing the promise and potential of African agriculture: Science and technology strategies for improving agricultural productivity and food security in Africa. Available at http://www .interacademycouncil.net/?id=10015. IAC, the Netherlands.

ICSU. 2006. Sustainable energy for sub-Saharan Africa: Science plan. Available at http:// www.icsu-africa.org/sustainable_energy_ rep_2007.pdf. Int. Council Sci. Unions Reg. Off. Africa (ICSU-ROA), Pretoria.

IEA. 2005. World energy outlook. IEA, Paris.

Integrated Framework. 2005. Tanzania: Diagnostic trade integration study. Vol. 2. Available at http://www .integratedframework.org/files/ Tanzania_DTIS_Vol2_Nov05.pdf. Integrated Framework for Trade-Related Tech. Assistance to Least Developed Countries, Geneva.

IPCC. 2007. Climate change 2007: Impacts, adaptation, and vulnerability. Working group II contribution to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge Univ. Press, UK.

Isaacs, M., M. Hara, and J. Raakjær-Nielsen. 2005. South African fisheries reform: Past, present and future? PLAAS Policy Brief No. 16. Univ. Western Cape, South Africa.

Isaacs, M., M. Hara, and J. Raakjær-Nielsen. 2007. Has reforming South African fisheries contributed to wealth redistribution and poverty alleviation? Ocean Coastal Manage. 50:301-313.

Jaffee, S. 2003. From challenge to opportunity: The transformation of the Kenyan fresh vegetable trade in the context of emerging food safety and other standards in Europe. ARD Disc. Pap. 2. World Bank, Washington DC.

Kane, S., T. Sallah, G. Alex, and K. van der Meer. 2004. Horticultural exports from developing countries. Agric. Investment Sourcebook Module 06. World Bank, Washington DC.

Kirschbaum, M.U.F. 2004. Direct and indirect climate change effects on photosynthesis and transpiration. Plant Biol. 6:242-253.

Mickels-Kokwe, G. 2006. Small-scale woodland based enterprises with outstanding economic potential: The case of honey in Zambia. CIFOR, Bogor.

MA. 2005a. Ecosystems and human well-being: Current state and trends Volume I-IV. Millennium Ecosystem Assessment, Island Press, Washington DC.

MA. 2005b. Subglobal scenarios in ecosystems and human well-being: Subglobal assessments. Millennium Ecosystem Assessment, Island Press, Washington DC.

MA. 2005c. Ecosystems and human well-being: Biodiversity synthesis. Millennium Ecosystem Assessment Island Press, Washington DC.

Minot, N., and M. Ngigi. 2004. Are Kenya's horticultural exports a replicable success story? 2020 Vision Briefs 12 No. 77. IFPRI, Washington DC.

Ndam, N., 2004. *Prunus africana*: A traditional medicine finds international fame. p. 33-36. *In* C. Lopez and P. Shanley (ed) Riches of the forests: For health life and spirit in Africa. CIFOR, Bogor.

Ndoye, O., and J.C. Tieguhong. 2004. Forest resources and rural livelihoods: The conflict between timber and non-timber forest products in the Congo Basin. Scand. J. For. Res. 19(S4):1-9.

Neiland, A.E., S. Chimatiro, U. Khalifa, B.M.B. Ladu, and D. Nyeko. 2005. Inland fisheries in Africa: Key issues and future investment opportunities for sustainable development. NAGA Q. 28:3-4. World Fish Center, Penang.

NEPAD. 2001. A new African iniative. Merger of the millennium partnership for the African recovery programme (map) and omega plan. Available at http://www.nepad .org.ng/PDF/About%20Nepad/NAI.pdf. NEPAD, South Africa.

NEPAD. 2004. Implementing the comprehensive Africa agriculture development programme and restoring food security in Africa. Available at www.nepad .org/2005/files/documents/172.pdf. NEPAD, South Africa.

NEPAD. 2005. Africa fish for all. NEPAD Fish for All Summit, Abuja, 22-25 Aug 2005. NEPAD, WorldFish Center, FAO, Rome.

Ngono, L.D., and O. Ndoye. 2004. Njansang and bush mango: Cameroonian seeds in national and international markets. p. 21-24. *In* C. Lopez and P. Shanley (ed) Riches of the forests: For health life and spirit in Africa. CIFOR, Bogor.

NRI. 2002. Smallholders in export horticulture: A guide to best practices. Nat. Resources Inst., Kent.

Ponte, S., J. Raakjær-Nielsen, and L. Campling. 2005. Trade and competitiveness in African fish exports: Impacts of WTO and EU negotiations and regulation. Trade Brief no. 5/2005. Trade Law Centre Southern Africa, Stellenbosch, South Africa.

Ponte, S., J. Raakjær-Nielsen, and L. Campling. 2007. Swimming upstream: Market access for African fish exports in the context of WTO and EU negotiations and regulationDev. Policy Rev.25:113-138.

Raakjær-Nielsen, J., and M. Hara. 2006. Transformation of South African industrial fisheries. Marine Policy 30:43-50.

Raakjær-Nielsen, J., P. Degnbol, K.K. Viswanathan, M. Ahmed, M. Hara, and N.M.R Abdullah. 2004. Fisheries co-management: An institutional innovation? Lessons from South East Asia and Southern Africa. Marine Policy 28:151-160.

Rosegrant, M.W., S. Meijer, and S.A. Cline. 2002. International model for policy analysis of agricultural commodities and trade (IMPACT): Model description. IFPRI, Washington DC.

Rosegrant, M.W., M.S. Paisner, S. Meijer, and J. Witcover. 2001. 2020 Global food outlook: Trends, alternatives, and choices. IFPRI, Washington DC.

Russo, L., P. Vantomme, F. Ndeckere-Ziangba, and S.Walter. 1996. Non-wood forest products. Chap.10. *In* Global forest resource assessment 2000. Available at http://www .fao.org/docrep/004/y1997e/ y1997e00.HTM. FAO, Rome.

Scott, G., M.W. Rosegrant, and C. Ringler. 2000. Roots and tubers for the 21st Century: Trends, projections, and policy options. 2020 Vision Disc. Pap. 31. IFPRI, Washington DC.

Sebitosi A.B., and P. Pillay. 2005. Energy services in sub-Saharan Africa: How conducive is the environment? Energy Policy 33:2044-2051.

Smeets, E.M.W., and A.P.C. Faaij. 2006. Bioenergy potentials from forestry in 2050. An assessment of the drivers that determine the potentials. Clim. Change 81:353-390.

Smeets, E.M.W., A. Faaij, I. Lewandowski, and W.C. Turkenburg. 2007. A bottom-up assessment and review of global bio-energy potentials to 2. Progress Energy Combust. Sci. 33:56-106.

Smelt, A., and A. Jager. 2002. Review of the impact of changes in EU pesticides legislation (Dir. 2000/42/EG) on fresh food exports from developing countries in the EU. Univ. Wageningen, Netherlands.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar et al. 2007. Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. Agric. Ecosyst. Environ. 118:6-28.

Sonne, N. 2001. Non-timber forest products in the Campo Ma'an project area. A case study of the North Eastern periphery of the Campo Ma'an National Park, South Cameroon. World Bank/GEF Biodiversity and Management Project. World Bank, Washington DC.

Temu, A.E., and A.A. Temu. 2006. How can the poor benefit from the growing markets for high value agricultural products? High

Value Agric. Production Workshop, Cali, 3-5 Oct 2005. Available at http://www.fao.org/docs/eims/upload/210989/regional_SSA.pdf. CIAT, Cali.
Thorpe, A. 2004. Mainstreaming fisheries into national development and poverty reduction strategies. Circ. 997. FAO, Rome.
Thorpe, A., C. Reid, R. van Anrooy, and C. Brugere. 2004. African poverty reduction strategy programmes and the fisheries sector: Current situation and opportunities. African Dev. Bank, Blackwell Publ., Oxford.
Tieguhong, J.C. 2003. Review of forest charges mechanisms for non wood forest products (NWFPs) and forest services in Africa. Consultancy Report. FAO, Rome.
UNEP. 2004. CDM information and guidebook. 2nd ed. UNEP Riso Nat. Lab., Denmark.
UNEP. 2006a. Africa environment outlook 2. Our environment, our wealth. UNEP, Nairobi.
UNEP. 2006b. Lake Victoria basin environment outlook. UNEP, Nairobi.
Veron, J. 2007. Half the world's population is urban. Available at http://www.ined.fr/fichier/t_telechargement/13943/telechargement_fichier_en_publi_pdf2_pesa435.pdf. Popul. Societies No. 435, June.
Von Blottnitz, H., and M.A. Curran. 2007. A review of assessments conducted on bio-ethanol as a transportation fuel from a net energy, greenhouse gas, and environmental life cycle perspective. J. Cleaner Prod. 15:607-619.
Wilson, D.C., J. Raakjær and P. Degnbol. 2006. Local ecological knowledge and practical fisheries management in the tropics: A policy brief. Marine Policy 30:794-801.
Woods, J. 2006. Science and technology options for harnessing bioenergy potential. Bioenergy and agriculture: Promises and challenges. Focus 14, Brief 6 of 12. IFPRI, Washington DC.
Woods, J., B. Gareth, and J. Lindsey. 2005. Producing ethanol, electricity and heat from sugar crops in southern Africa: Policy status and prospects in a rapidly changing global environment. CARENSA, South Africa.
World Bank. 2006. Carbon finance annual report 2005. Carbon finance for sustainable development. World Bank, Washington DC.
WorldFish Center. 2005. Fish and food security in Africa. WorldFish Center, Penang.
WTO (World Tourism Organization). 2005. Yearbook of tourism statistics: 1999-2003. WTO, Madrid.
Xenopoulos, M.A., D.M. Lodge, J. Alcamo, M. Marker, R. Schulze, and D.P. van Vuuren. 2005. Scenarios of freshwater fish extinctions from climate change and water withdrawal. Global Change Biol. 11:1557-1564.

5

Options for Action: Generation, Access and Application of AKST

Coordinating Lead Authors:
Joan Kagwanja (Kenya) and Elizabeth Robinson (UK)

Lead Authors:
Evelyn Apili (Uganda), Gezahegne Ayele (Ethiopia), John Bakang (Ghana), Chiedza L. Muchopa (Zimbabwe)

Contributing authors:
Wisdom Akpalu (Ghana), Susan Kaaria (Kenya), Razack Lokina (Tanzania)

Review Editors:
Assefa Admassie (Ethiopia) and Aduni Sanni (Nigeria)

Key Messages

Key Messages

1. The expected structural transformation of sub-Saharan Africa's economy is not expected to diminish the importance of agriculture to the region's socioeconomic development, both as a source of livelihoods and as a linkage to other sectors. The fostering of participatory and decentralized structures of governance inclusive of farmers, marginalized groups, regional and local authorities, and enterprise is an important step toward the development of the agricultural sector. Decentralization of funding sources and market development, including an emphasis on the cross-sectoral benefits of agriculture (to health, nutrition, education, environment), regional market-chain approaches and local government funding can raise the profile and contribution of agriculture for development.

2. The presentation of a "basket" of agricultural technology options, would allow farmers the flexibility to choose among options that best match the site-specific diversity of their fields and socioeconomic contexts. This approach is in contrast to the typical approach in which only a small number of technologies are made available through extension services. Almost 90% of sub-Saharan African farmers currently practice diversified agricultural production systems. Participatory and community-driven approaches to research and technology development can increase both the relevance of AKST for small-scale producers and their likelihood to adopt new technologies and practices. Research and extension efforts can improve rates of adoption by addressing concerns of language and gender.

3. Markets for agricultural products remain relatively inaccessible to sub-Saharan African farmers. Technical assistance, extension and capacity development is needed to link producers to markets and transform farming activities into agribusiness ventures. Improvements to basic infrastructure, market information systems and levels of market integration are critical.

4. There is a large scope for increasing the role and participation of women in agricultural research, extension and development. Women account for over 70% of agricultural workers and 80% of food processors in sub-Saharan Africa, yet comprise 17% of agricultural extension workers. Increased access for women to microfinance and education is likely to increase the involvement and adoption of AKST by women.

5. Land degradation, and poor soil fertility in particular, is a critical factor in limiting agricultural production in SSA. Options for soil, water, and nutrient management exist; approaches that address resource management in an integrated way are more likely to offer sustainable solutions than practices that focus on management of a single resource.

6. The full extent and long-term economic costs of environmental degradation to individual farms and agricultural landscapes is seldom clear to farmers or decision makers. Increased understanding and information flow of the full costs of environmental degradation at all scales is a critical step to the design of policies and incentives that can simultaneously support long-term sustainable development and agricultural production. Land tenure and access to credit are key elements to improving rural livelihoods in an equitable fashion.

7. *In situ* conservation is the most appropriate means to preserve the indigenous germplasm and seed varieties that sustain the majority of small-scale rural farmers. Agricultural intensification is most often accompanied by a decrease in agricultural biodiversity. Conservation of biodiversity requires the involvement of local communities and can be facilitated by government-funded initiatives. Strategies for the preservation of wildlife biodiversity are significantly improved when local communities are active in the responsible organizations.

8. A *de facto* open access situation is typical of forested lands in SSA. The contribution of Payment for Ecosystem Services (PES) and other market-based schemes to address deforestation is as yet unknown. Agroforestry, simultaneously offering improvements in soil fertility, provision of animal fodder, and the supply of poles, timber and fuelwood holds the potential in the short and long term to relieve pressure on forested lands.

9. Centralized fisheries management strategies hold limited potential for addressing the poverty of fisheries-dependent populations. Current limitations in technical capacity, funding levels and management schemes have left most fisheries overexploited. Aquaculture holds some potential to relieve pressures on fish stocks and will require significant cooperation between fishers and governments and between fishing communities.

10. Agriculture policies in SSA continue to primarily promote production, reducing the potential of agriculture to contribute to the improved health and nutritional status of households through the production and consumption of diverse and micronutrient-rich foods.

5.1 Governance, Institutions, and Funding

Agriculture plays a central role in the livelihoods of the majority of sub-Saharan Africans, providing the basis for social and economic development and providing crucial linkages to environmental sustainability, peace and security. While a structural transformation of SSA economies is expected to see agriculture contribute relatively less to employment creation and GDP, in absolute terms agriculture is expected to contribute even more to sub-Saharan Africa's socioeconomic development, by providing vital linkages to other sectors of SSA economies, especially manufacturing, industries and the service sector. AKST has a significant role to play in facilitating a viable transformation of SSA economies by enhancing agricultural productivity and increasing rural incomes. An economically viable and environmentally sound agricultural transformation strategy would include harnessing AKST to increase efficiency and sustainability in farm production, agro-industrial and product development, and improvements in distribution and marketing networks.

A vision for enabling the sector to reach development and sustainability goals. Increasingly there is a consensus that a new vision for agriculture in SSA is required, articulated through various organizations. The Forum for Agricultural Research in Africa's (FARA) vision is for African agriculture to become vibrant and competitive in the international market, growing at a rate of at least 6% per annum by the year 2020 (FARA, 2007). NEPAD's vision includes an agriculture-led development that eliminates hunger, reduces poverty and food insecurity and includes improving access to markets to integrate more farmers into the market economy (NEPAD, 2004).

Key tenets expressed by many individuals involved in policy making, are decentralization and the adoption of a value chain approach, embedded within an environment of good governance. Definitions of good governance invariably include elements of democratic decentralization, enforcement of law and order—including the elimination of corruption, properly enforced legal frameworks—and participatory, transparent and equitable processes (UNESCAP, 2007). An environment of good governance for the generation and application of AKST would include empowerment of farmers to take on a larger role in agricultural research and development; activities to ensure the inclusion of marginalized groups such as women and pastoralists; decentralization of economic and political structures of governance; promotion of the principles of subsidiarity and plurality in service provision; use of local and traditional knowledge, and private and public sector skills; and well defined and enforced property rights.

Given that many SSA countries are relatively small in terms of geography and population, with many having similar sociocultural and agroecological similarities across borders, a regional approach to value chain development has been advocated (UNECA, 2007). To African and other investors in agriculture and AKST, regional integration in the context of value chain development would allow for the much needed spatial and population sizes critical to viable production, processing, distribution and market expansion. Increased trade opportunities associated with regional integration, in particular, would help to facilitate private sector involvement and ultimately, market led productivity and production improvements. Given that Africa has, during the 2006 African Food Security Summit, identified regional strategic commodities, using these commodities as entry points for a regional approach to value chain development offers an opportunity to realize the benefits of this new vision to agricultural development in Africa.

The current institutional environment in many SSA countries is not always conducive to developing the agricultural sector. At the country level, AKST is often poorly represented in negotiations with finance ministers and other key players. This situation is exacerbated by agriculture often being represented in multiple ministries, which makes national coordination tricky even for the agricultural sector, let alone links between agriculture and other sectors. Countries have two broad options, to attempt to coordinate agricultural and AKST activities at the national level or to coordinate at the level of decentralization. As coordination occurs at a more decentralized level, the complexity of developing a national strategy can be reduced.

Arguments have been put forward that the key role for governments and agriculture in SSA is not about public expenditure, but rather about policy making and regulation. Agriculture is primarily market-based. Even in SSA many of the small-scale producers who are currently producing for home consumption would be involved in the market if they were not constrained by, for example, high transaction costs or lack of credit. The role of government becomes one of correcting for market failures and distributional objectives.

The current and likely future of AKST in SSA, at least in the short term, is one of unreliable funds for AKST generation, access, development and extension and inadequate human capacity. When compared with other regions, spending on the agricultural sector in SSA does not appear disproportionately low. Indeed, total public spending on agricultural R&D as a percentage of agricultural output (agricultural GDP)—the intensity ratio—in SSA (48 countries) in 1995 was 0.79%, greater than the average for all developing countries (0.62%) though lower than the global average. However, the trend has been downward in SSA. Spending in SSA grew by only 0.82% in the 1990s as compared with 1.25% in the 1980s, and the intensity ratio in 2000 was down to 0.7%. The World Bank recommends a ratio of 2%, whereas other organizations have suggested 1% as more realistic (Beintema and Stads, 2006). There is considerable variation among countries in SSA, from 0.20% or lower in Gambia and Niger, to over 3.0% in Botswana, Mauritius, and South Africa (Beintema and Stads, 2006). To reach either recommended level requires increased spending in most countries. Given that the number of research staff in the region (sample of 27 countries) has been growing at approximately 4% per year over the past three decades, average spending per scientist has declined by about half over this period.

Donor funds. Traditionally donors have taken an area-based approach to their agricultural activities. Yet a value chain perspective on agricultural development lends itself more to a commodity-based focus that would fit better with a value chain approach and use limited funds more effectively. At the regional level, AKST is almost always a stand-alone activity in donor programs rather than being part of an integrated research-development-application approach (Rothschild, 2005). Effective donor involvement is further constrained by a project-oriented approach, including limited time commitments and a lack of coordination (Tripp, 2003). The Commission for Africa has advocated for increased aid to SSA—that is untied, predictable, harmonized and linked to the decision making and budget processes of the country receiving it—for an increased growth rate and progress towards achieving development goals (www.commissionforAfrica.org; Commission for Africa, 2005). Indeed, as direct budgetary support through country offices of donor agencies becomes the preferred mode of overseas development assistance, the constraints to effective donor involvement may be reduced. Poor representation of agriculture at the national level may become an increasing problem (Rothschild, 2005) unless mechanisms are in place to raise the profile of agriculture and availability of funding for AKST.

Leveraging funding. The profile of agriculture can be raised through its links with health, nutrition, and environmental goals. For example, NEPAD's Comprehensive Africa Agriculture Development Programme (CAADP) was endorsed by the African Heads of States and Government Summit as a framework for restoring agriculture growth, food security and rural development in Africa. CAADP has been receiving substantial support since agriculture was placed at the top of Africa's development agenda through the Maputo Declaration, which commits governments to allocate 10% of public investment for agricultural development (Heidhues et al., 2004).

There is potential for leveraging funding for agriculture by highlighting (and preferably quantifying) the potential positive contribution of agriculture to health, nutrition and the environment. For example, health considerations typically play little if any role in the decisions made in ministries of agriculture, despite the large potential health benefits from joint research and action in agriculture and health (Hawkes and Ruel, 2006). Similarly, health and agriculture are rarely considered interdependent by donor agencies or even government departments when budgets and strategies are being determined. In Malawi, over half of child mortality can be attributed to malnutrition, as much as the combined so-called killer diseases (Rothschild, 2005). There is therefore scope for arguing that part of the health budget would be well spent reducing child mortality through improvements in agriculture. In Uganda, collaboration between UK DFID economics and environment advisers resulted in the integration of environmental issues into both policy and investment mechanisms of the Plan for the Modernisation of Agriculture (Yaron and White, 2002).

Without increased awareness and cooperation among agriculture and health ministries, AKST is likely to continue to focus on increased output rather than nutritional quality and diversity. The CGIAR centers have recently begun an initiative on agriculture and health that could potentially contribute to increased coordination between ministries of health and agriculture and among countries in the region. Networking national bodies with regional bodies such as NEPAD and international organizations such as FAO and WHO, also offers potential.

Networks have the potential to use scarce funding and expertise more effectively and can address some shortcomings, such as low funding and fragmented agricultural research capacity. Despite increases in AKST capacity in the 1970s and 1980s, more than half the region's countries each employ fewer than 100 full-time equivalent researchers, and 40% of total capacity lies within just five countries. Increased reliance on networks brings with problems of complexity that can negate benefits and SSA's ability to benefit from network synergies is likely to be constrained by the current lack of sufficient capacity. The question of whether or not the benefits of regional cooperation and integration outweigh the costs has not been evaluated sufficiently (Toure, 2003). The increased use of networks for AKST research and development is particularly challenging given an emphasis on farmer participation, particularly in areas where research is becoming more site specific (Burley, 1987).

The involvement of the private sector. Globally, there has been a gradual shift away from government and donor funding, a trend which is likely to continue. Although in the short and medium term, private sector investments in AKST are likely to remain small in SSA (currently less than 2% of research spending) due in part to the lack of funding incentives (Beintema and Stads, 2006), funding mechanisms that are likely to increase in importance include commodity levies, internally generated resources, local government funding and commercial contracts (IAC, 2004).

Significant debates remain over the role and involvement of the private sector in AKST research and development. A continuing question is whether countries in SSA should rely exclusively on approaches by established science centers of excellence, or involve the private sector in public-private partnerships. Private sector R&D has tended to focus on improving crops and technologies relevant to farmers in richer countries, ignoring crops important to poor farmers because of the lower profit potential of the latter. Private public partnerships offer the possibility of a focus on poorer farmers combined with access to the better equipment and facilities that private companies often have (IFPRI, 2005). However, such approaches could draw public funds away from R&D relevant to poor farmers toward high-return commercial crops. Findings from Latin America suggest that partnerships work best when the parties have a shared goal or interest in a particular outcome and the benefits of working together outweigh the costs of conducting the research separately (Hartwich et al., 2007). These partnerships raise critical issues concerning intellectual property rights. For example:

"To develop golden rice . . . Potrykus and Beyer used proprietary technologies belonging to half a dozen different companies. . . . After the initial research the first step was to arrange for free licenses for these technologies so that Potrykus and Beyer could use them to further develop golden rice varieties. Syngenta then made legal arrangements giving the intellectual property rights associated with golden rice to a group called the Golden Rice Humanitarian Board, chaired by Potrykus and made up of individuals from various public and private organizations. The Humanitarian Board grants royalty-free sublicenses to the golden rice technology to public research institutions so they can develop locally adapted varieties in places like Bangladesh, China, India, and the Philippines. For developing country farmers who generate more than US$10,000 a year from farming, a commercial license from Syngenta is required. Otherwise, the technology is free for use by farmers in developing countries. Working out such an arrangement took considerable time" (IFPRI, 2005).

5.2 Generation, Access and Application of AKST

5.2.1 Appropriate technologies

Globally, large productivity gains in agriculture have been achieved through monocropping systems that benefit from specialization and economies of scale. In SSA, given that almost 90% of African farmers currently practice diversified production, a more pragmatic approach may be to optimize the farming systems already in place by exploiting the particular advantages of these systems (IAC, 2004). Indeed, many technologies in SSA remain "on the shelf", in part because they are relevant to specialized rather than diversified systems and in part because they are not relevant to the particular environmental characteristics of the region. For development and sustainability goals to be reached, new technologies will need to address the sustainability of the agricultural systems themselves and the impact they have on non-agricultural ecosystems that provide services important for improving livelihoods and the environment.

There is a growing consensus that collaborative research with local farmers and groups, and putting local people's perspectives at the center of research efforts is the best way forward, particularly for small-scale diversified farms. Yet there is little evidence as to whether such approaches are likely to be successful in the future, and knowledge on how to operationalize them (Omamo, 2003). Many of the recommendations are not evidence based, but rather advocate new and intuitively appealing approaches. However, SSA's poor agricultural performance relative to other regions suggests that a change is needed. Given the criticisms of earlier AKST developments (technologies that are inadequately responsive to farmer needs and based on unrealistic results from experimental stations), more inclusive non-linear approaches may be more successful.

5.2.1.1 Participatory approaches to R&D

Participatory approaches are increasingly accepted by many stakeholders as a way of increasing the likelihood that farming solutions will be adopted by farmers (Ashby et al., 2000; Ngugi, 2005.) Participatory plant breeding (PPB) and farmer participatory research processes decentralize control over the research agenda and permit a broader set of stakeholders to become involved in research, thereby also addressing the different needs of men and women for technical innovation. The paradigm of involving farmers in research is based on strong evidence (Pretty and Hine, 2001) that enhancing farmers' technical skills and research capabilities and involving them as decision makers in the technology development process results in innovations that are more responsive to their priorities, needs and constraints. This is an important strategy in making research more demand-driven and responsive to the growing needs of farmers and can contribute to the development of technologies that meet the needs and priorities of farmers. Many of the participatory approaches that have been proposed or implemented reflect the diversity of farmers' fields and socioeconomic circumstances and illustrate clear differences between controlled scientific off-farm experiments and the reality of farming in much of SSA. The development and adoption of a diverse range of technologies for water harvesting and conservation in East Africa has been attributed in part to the adoption of community-based participatory approaches in place of the traditional top-down approach to technology research and extension (Lundgren, 1993).

In general participatory approaches have not been proven as yet to be more effective than earlier approaches (Farrington and Martin, 1988; Bentley, 1994), and may be constrained by the existing institutional structures in many SSA countries, including the NARS system (Hall and Nahdy, 1999). A number of specific drawbacks to and criticisms of farmer-led and participatory approaches have been identified. First, there has been a tendency for these approaches to emphasize food security, with insufficient attention paid to development of the value chain through marketed and value-added goods. Increasing the involvement of the private sector and recognizing the role of the market could increase the relevance and further adoption of appropriate technologies (Heemskerk et al., 2003). Second, participatory approaches have typically been used for applied and adaptive research and technology transfer, and so they have not as yet been a source of significant scientific data (Probst et al., 2003). This is in part due to the lack of scientists involved in longer-term participatory research, which is a consequence of a rewards system based on the generation of data at meso and macro levels (Probst et al., 2003).

It may not be possible to have statistically valid results from participatory trials because of the high variance in farmers' fields. Rather, the aim might be to get results that are satisfactory within the context of a particular production system that, again, are difficult to publish in more traditional scientific journals (Mavedzenge et al., 1999). Third, participatory and integrated approaches tend to be local, often incorporating specific local and traditional knowledge, and so are difficult to scale up and are often costly relative to their impact. Where approaches have proven to be locally successful when working with a farmer group or a community, a key issue is to understand how participatory approaches can be adapted and used with large numbers of farmers to achieve wider impact, while still retaining the expected human and social capital benefits of participation. Finally, even in situations where research benefits from supply-led approaches, the needs, demands and circumstances of farmers in SSA can inform the research directions (Rothschild, 2005). For example, there are many examples of successful integrated pest and disease management projects, as well as work on climate change adaptation that have been led by scientists but have incorporated a participatory approach.

One outstanding factor that has received little attention in the participatory development discourse as it pertains to agricultural extension in SSA is that of language. Projects and agencies concerned with agricultural development tend to function in languages different from those that farmers and rural communities use in their livelihoods and for communicating local knowledge (Chaudenson, 2004). It is not possible to say that this is a cause for the poor performance of agriculture, but it is a factor that is underresearched. SSA is the only region where formal education and government services function in languages different from the first languages of almost the entire citizenry. There is anecdotal evidence that this "linguistic divide" in SSA agriculture leads to poor understanding of science and technology (Fagerberg-Diallo, 2002). Farmer participation may require the use of local languages in order to be responsive to farmers' needs. Despite shortcomings, a number of specific participatory approaches have the potential to improve the likely impact of AKST.

5.2.1.2 Technologies responsive to diverse farming systems

A participatory approach that is gaining support is the development of a basket of prototype technologies that match the diversity of farmers' fields (Weber, 1996; Wezel and Rath, 2002). Under this approach, researchers would not look to the "best" technology under relatively controlled circumstances, but rather would work with farmers to develop a range of technologies (whether those technologies are developed by farmers, scientists, collaborative efforts or adapted from traditional and local practices) that are resilient to the high weather variability, resource availability and market fluctuations. For example, many technologies are known only to a small number of farmers, yet may have broader potential. These can be identified, validated and then incorporated into baskets of technology choices including agricultural engineering hardware. This approach is in contrast to the typical approach in SSA in which a small number of technologies are identified as promising by scientists and then made available to farmers through extension activities. Using a basket approach, farmers take up the technology best suited to their own specific conditions (including soil types, water availability and variability, access to credit and insurance). Small-scale holders in many parts of the world including SSA have been shown to best operate and adopt technologies when they understand their farming systems (Hall, 2001). As yet there is limited evidence that such a new approach is more successful than traditional research and extension.

Learn from other regions. Over the past 20 years, CIAT has accumulated considerable experience in developing, using and promoting participatory research approaches and other innovative methods to enhance agricultural research for development that are appropriate for poor farmers (Ashby et al., 2000). The Comité de Investigación Agrícola Local (CIAL), or Local Agricultural Research Committee is a farmer-run research service that is answerable to the local community. A committee of farmers is chosen for their interest in research and willingness to serve. The CIAL conducts research on priority topics identified through a diagnostic process, in which all are invited to participate. After each experiment the CIAL reports its results back to the community. Each committee has a small fund to offset the costs and risks of research and is supported by a trained facilitator until the committee is able to manage the process independently. There are over 400 CIALs in eight countries in Latin America and the Caribbean. Several studies have been conducted to assess the impacts of these types of empowering approaches on technology adoption and livelihoods. Farmer participation at different design stages may affect the direction of research, identify different priorities and other beneficiaries and can impact the design of the technology, as well as the adoption or acceptance of it by the intended users (Lilja, 2003).

Farmer participation at the early stages of technology development has been found to be important in improving the relevance and appropriateness of the technologies and therefore enhancing their potential impact (Johnson et al., 2003). For example, as a direct result of farmer participation in the design stage of the research process, a project shifted its focus from integrated pest management (IPM) to integrated crop management (ICM), thereby broadening the project to include varietal selection, seed and plant health, nutrient management, and economics and marketing. This change had significant implications on the adoption and acceptability of the project results. The International Center for Tropical Agriculture (CIAT) is now adapting and evaluating these types of empowering participatory research approaches in East and Central Africa.

Participatory technology and product development. Community driven development (CDD) is an attempt to give control of decisions and resources to community groups, which usually work in partnership with demand-responsive support organizations and service providers, among them elected governments, central government agencies, the private sector and NGOs (Dongier, 2002). The CDD approach to development attempts to empower poor people, organize economic activity and resource management, provide social infrastructure services, improve governance, and enhance the security of the poorest members of society. The potential for CDD is greatest for goods and services that are small in scale, not complex and require local cooperation, such as common pool goods like pastures and surface water irrigation systems, public goods such as local road maintenance, and civil goods such as public advocacy and social monitoring.

Experience demonstrates that by directly relying on poor people to drive development activities, treating them as assets and partners in the development process and building on their institutions and resources, CDD has the potential to make agricultural development and poverty reduction efforts more demand responsive, more inclusive, more sustainable, and more cost-effective than traditionally centralized approaches. CDD is more likely to be effective if some conditions are met:

- Local government institutions are strengthened to provide organizational and technical support, adequate resources, decision-making authority and mechanisms for grassroots participation;
- Rural communities and farmers' associations are entrusted with legal authority and are able to build their capacity to take full part in agricultural development matters (e.g., contracting loans, initiating and implementing programs and projects);
- Linkages are created between research institutions, extension services and technology users for exchange of knowledge and experience on relevant development issues; and
- Legal and financial frameworks are developed that encourage local communities to claim ownership of these services and infrastructure.

CDD practices have shown encouraging results in Senegal, Tanzania and India. In India, several modest experiments started in the 1990s to empower local communities with resources and authority. The outcomes have been dramatically successful in several cases and resulted in poverty reduction. A key lesson from countries' experiences is that, given clear rules of the game, access to information, and appropriate capacity and financial support, poor men and women can effectively organize in order to identify community priorities and address local problems, and work in partnership with local governments and other institutions.

5.2.1.3 Agricultural extension and capacity-building opportunities

Although rural communities in SSA have a long history of self-help and community development, top-down approaches to the development and dissemination of AKST have traditionally been the norm. As such, rural communities typically have not been empowered with resources and decision-making authority, and the voices of socially excluded groups such as women and minorities are often not heard. Typically, extension organizations in the region have involved overlapping responsibilities and uncoordinated interventions between several public agencies and NGOs, with extension workers often lacking minimum means, such as vehicles, fuel and materials to fulfill their roles. In many SSA countries the linear approach of a centralized scientific organization transferring technologies down to extension agents and on to the farmers (reinforced by education systems that train scientists specifically to work in such institutions) has worked relatively well for major cash crops. However, this system has had little success for improving subsistence and food production (Hall and Nahdy, 1999). The typical linear approaches to extension that have been employed in SSA lack feedback loops from farmers to researchers and value "scientific" research and learning over more tacit forms of farmer learning and local and traditional knowledge (Ochieng, 2007).

Participatory Demonstration and Training Extension System (PADETES) has been the national extension system of Ethiopia. Developed after a critical evaluation of the past extension approaches practiced in Ethiopia, this system accommodates present thinking in extension philosophy including research, education and extension as part of the knowledge system. PADETES puts equal emphasis on human resource development and the transfer of appropriate and proven technologies. Implementing extension services is entirely the responsibility of the Regional Agricultural Bureaus, while the Federal Ministry of Agriculture has the mandate to formulate and submit agricultural and related policies and, upon approval, coordinate and disseminate them through interregional development programs and/or projects and provide technical advice and training services to the extension staff of the Regional Agricultural Bureaus (Ejigu, 1999).

A number of approaches already exist to train farmers in research and extension. Farmer field schools (FFS) employ a pedagogical approach of "learning by doing" or "interactive learning" (Ochieng, 2007) that can improve farmers' knowledge, skills and sense of empowerment. Farmer field schools also allow local and traditional knowledge to be incorporated into the development of new approaches. Farmer field schools, combined with efforts to generate demand, have been successful in establishing producer and consumer markets for vitamin A enriched orange-fleshed sweet potato in east and southern Africa (Ochieng, 2007). Farmer field school shortcomings include relatively high investment costs; expensive to sustain and to replicate; and they tend to exclude poorer farmers (Davis, 2006).

Farmer field schools suffer from the same problem as other forms of public extension, namely they require sustained funding. In Kenya, extension-led farmer field schools can cost up to $600 per group of 25-30 farmers whereas farmer-led schools cost half of that (Onduru et al., 2002). Once grants from the International Fund for Agricultural Development Integrated Production and Pest Management (IFAD-IPPM) are depleted, these FFS are likely to cease unless local self-financing initiatives are identified (Onduru et al., 2002). Given the reported large increases in yields, there may be potential for FFS to be self-financed by the farmer groups themselves, as has happened in other areas in Kenya.

Lessons from FFS can be documented in relatively simple extension messages (Onduru et al., 2002). In Uganda, there has been a move to decentralize extension services and to encourage a plurality of providers and approaches. Particularly important is that extension services are being designed to be more directly responsive to farmers' self-identified needs.

New approaches to extension that are more responsive to farmers, less top down and more integrated with research will require extension agents to have different skills from those they currently have and that are traditionally available. One option is to introduce mid-career training and diploma courses, as is being done in Uganda. Fee-based schemes are being introduced in part in response to a decline in public funding of extension services. This approach can expand the provision of extension services, but may exclude the poorest farmers. Increasingly, the private sector is becoming involved in the provision of extension services. Private extension services are typically linked to the provision of inputs such as seeds and fertilizer and the purchase of agricultural products.

NARS relevance to changing AKST paradigms. In many countries in SSA, most agricultural research is undertaken within the framework of the NARS and so is conditioned by these institutions (Hall and Nahdy, 1999). The adoption of participatory approaches within the NARS framework is hindered by issues of professional identity, lack of participatory research skills, and a professional reward system that makes it difficult to publish the findings from participatory research in the top academic journals (Hall and Nahdy, 1999). Extension tends to rely only on countries' official languages as working languages. Though not yet proven, moving the use of selected SSA languages up the research-extension chain could have a significant impact on participation, relevance and results.

There are a number of processes currently working to improve the relevance of the NARS. The Innovation Systems Framework and Integrated Agriculture Research for Development are highlighted below. An innovation system can be defined as networks of organizations or actors, and the institutions and policies that affect their innovative behavior and performance that bring about new products, new processes and new forms of organization into economic use (Hall et al., 2006). As an evolutionary model, the focus is on interaction between actors and their embeddedness in an institutional and policy context. Many actors in the public and private sectors could be involved in the creation, diffusion, adaptation and use of knowledge relevant to agricultural production and marketing. Instead of regarding public research and extension agencies as the prime movers of agricultural processes, the innovation systems framework recognizes that 1) a broad spectrum of actors outside the State have an important role; 2) the relative importance of different actors changes during the innovation process; 3) as circumstances change and as actors learn, roles can evolve; and 4) actors can play multiple roles —sometimes as a sources of knowledge, sometimes as seekers of knowledge and sometimes as a coordinator of linkages between others (Hall et al., 2004).

The innovation systems concept recognizes that the inclusion of stakeholders and their demands can shape the focus and direction of innovation processes. The processes are not articulated by the market alone but can be expressed through a number of other channels, such as collaborative relationships between users and producers of knowledge or mutual participation in organizational governance (for example, board membership). This framework is now being tested in various contexts in SSA.

The Forum for Agricultural Research in Africa (FARA) is testing innovative partnership processes, or "Innovation Platforms," which seek to better understand how processes for systemic innovation can be organized among researchers, practitioners, policy actors, market chain actors and rural communities in order to make innovations useful, affordable and accessible to end users (Box 5-1). The Innovation Platforms will serve to provide a space (not necessary physical) around which stakeholders will organize around particular themes. A common Innovation Platform will bring together researchers from different disciplines, private sector (input suppliers, output markets, market information systems, microfinance institutions), practitioners (NGOs, extension departments), decision makers, rural communities and farmer organizations. This approach is being tested and evaluated in various countries under the SSA Challenge program (FARA, 2007).

Box 5-1. New agricultural initiatives that seek to address AKST and natural resources.

NEPAD: Agriculture is one of NEPAD's ten sectoral priorities, within which activities at the national and international level include protecting natural resources through proposed interventions such as integrated land and water management, on-farm and small-scale irrigation development, land improvement, and the upgrading and rehabilitation of existing large-scale irrigation projects (Njobe, 2003).

IFAD: In west and central Africa, IFAD's priorities include increasing agricultural and natural resource productivity; and improving poor rural people's access to, and management of, land and water (http://www.ifad.org).

FARA: FARA's Sub Saharan Africa Challenge Program (SSACP) "aims to address the most significant constraints to reviving agriculture in Africa which it identifies as failures of agricultural markets, inappropriate policies and natural resource degradation with a new paradigm, Integrated Agricultural Research for Development (IAR4D)". FARA hopes further to "foster synergies among disciplines and institutions along with a renewed commitment to change at all levels from farmers to national and international policy makers".

AHI: The African Highlands Initiative, a collaborative effort among National Agricultural Research Institutes (NARIs), International Agricultural Research Centers (IARCs) and various NGOs focuses on key natural resource management and agricultural productivity issues in the intensively cultivated highlands of East and Central Africa. The initiative aims to "development approaches and partnerships to develop and institutionalize effective and efficient approaches for sustainable integrated natural resource management (INRM) and enhanced productivity . . . promoting integrated, inter-institutional research and development efforts with strong community participation to solve critical issues of soil productivity, water and land-use" (http://www.africanhighlands.org/).

DMP: The Desert Margins Program, a collaborative effort convened by ICRISAT, aims to analyze the root causes of dryland degradation in Africa; document indigenous knowledge of sustainable practices; develop more sustainable practices; help governments design policies that encourage sustainable practices; enhance African institutional capacities for land degradation research and outreach; facilitate the sharing of technologies, knowledge and information; and forecast possible climate change scenarios for land use planning (the countries involved are Botswana, Burkina Faso, Kenya, Mali, Namibia, Niger, Senegal, South Africa and Zimbabwe; http://www.dmpafrica.net/index.htm).

5.2.2 Soil variability

A key challenge in SSA is the high variability of African soils, rendering blanket recommendations inappropriate for many farmers (Bindraban and Rabbinge, 2003). This high variability suggests that decision tools would complement a basket of available technologies and would also counter a criticism of participatory approaches—that they are difficult to scale up. Options for enabling such "precision agriculture" vary from high-tech satellite referencing to relatively simple scoring techniques based on farmer observations of their own fields (Gandah et al., 2000).

Linking systems modeling tools to farmer participatory research. Computer models have been developed that can be used to help resource-poor farmers in SSA determine the best use of, for example, crop residues, fertilizers and alterative land uses (Mando, 1997; Ibrahim et al., 1988; Sissoko, 1998; Sawadogo and Stamm, 2000; Slingerland, 2000; Kanté, 2001; Schiere et al., 2002). Systems modeling linked to farmer participatory research in sub-Saharan Africa can help farmers interact with scientists and speed up the research process (CIAT, 2002). Information and communications technologies (ICT), including geographic information systems (GIS), can help to increase understanding of complex biophysical conditions (Bindraban and Rabbinge, 2003). Participatory GIS provides a new set of approaches and methodologies with potential for advancing agricultural development in Africa.

Recent advances in ICT allow the search for optimal application of inputs in time and space, often by combining GIS and close and remote-sensing technologies and increase labor productivity. In many parts of Africa, e.g., Kenya, ICT has facilitated communication and provided farmers with market information, leading to improved negotiating power. Although in many parts of Africa these technologies have not yet been applied, success stories from countries such as India demonstrate their feasibility in poor regions. In addition, the use of ICT has enabled the availability of quality data sets on agricultural production for disaggregated agro-ecological areas with spatially defined heterogeneous production systems. In countries in SSA where ICTs are not yet capable of helping individual farmers, simple decision support tools can complement participatory approaches where farmers are encouraged to identify and adapt technologies to suit their own particular circumstances.

5.2.3 Patents for biotechnologies and GM technologies

In SSA, most food and feed crops are grown from farmer-saved seeds and farmer-developed varieties with little government or donor support. A key concern over agricultural biotechnology and GM in particular is that it can lead to the decommodification of the seeds that farmers use from one season to another, which would benefit developed countries at the expense of poorer countries (Fok et al., 2007). New technologies are often developed in richer countries and IPRs can claim global applicability.

Maintenance of patent exemptions. Because of this, a number of organizations, such as the WTO TRIPs Council, support the continuing of patent exemptions in SSA (Article 27.3b) and seek to protect the use of traditional AKST, such as at the World Intellectual Property Organization negotiations. SSA has also opposed attempts to restrict farmers' rights to save and exchange seeds at implementation negotiations of the Convention on Biological Diversity and the International Treaty on Plant Genetic Resources for Agriculture and Food. Such an approach is, consistent with the CGIAR system. For example, IITA explicitly states that it normally does not seek to secure patent or plant breeders' rights for germplasm, materials or technologies developed by IITA. Moreover, IITA does not see intellectual property protection as a mechanism for securing its own funding.

Laws for patenting in SSA. An alternative approach (promoted by a number of intergovernmental institutions, foundations and bilateral donors) is based on patenting seed varieties and other inputs and would require rewriting SSA law. Proponents of such an approach suggest that it will reduce biopiracy and foreign exploitation of local and traditional knowledge. Although the costs involved in securing patents would be too high for individual small-scale farmers, concessions could be negotiated by organizations such as the African Agricultural Technology Foundation (AATF) for local communities to benefit (as for the maize project where seed is coated with the herbicide imazapyr to control Striga). South Africa has an IPR regime that proponents suggest could provide a favorable environment for both local and foreign investment opportunities. Detractors suggest that an approach based on patents would protect patent holders' rights while eroding farmers' rights and would be excessively costly in terms of development, royalty and licensing costs.

There are alternatives to the two extreme options discussed above that can be explored in the future. Some gene and biotechnology patents that are expiring will become available to poorer countries. Patent protection for "global" crops could be reduced in poorer countries or enforcement could be permitted in either richer or poorer countries but not both (Fok et al., 2007). CAMBIA is an open-source system for biotechnology that has the express purpose of providing free and continuously evolving intellectual property for global users.

5.3 Enhancing Agricultural Product Value Chains

The lack of connection between the farmer and the market has seen SSA agriculture remain rudimentary, unprofitable and unresponsive to market demand. SSA markets, which are readily available to international agricultural products, are relatively inaccessible to SSA farmers. With recent and expected trends relating to market liberalization, decentralization, urbanization and globalization, SSA will continue to experience dramatic social, political, economic and cultural transformations. As such, SSA agriculture must respond to the needs of a different type of consumer, increasingly a better informed, urban-based consumer with a demand for more processed and easy-to-cook foods. SSA agriculture cannot remain rudimentary but must become an integral part of the growing African market economy through a transformation geared towards increased agricultural incomes and employment and competitiveness in local, regional and international markets.

Part of the reason for the current underdevelopment of SSA agriculture lies in the failure to transform farming activities into agribusiness ventures, which are key to developing the various stages of the agricultural product value chain and crucial to linking agriculture to markets. Agribusiness refers to all market and private entities involved in the production, storage, distribution and processing of agricultural products plus the supply of production inputs, extension, administration and research. There are signs that agribusiness development is imminent in SSA, e.g., the recent growth in post-production activities; trends towards more vertically linked and concentrated organizations in agrifood systems; opportunities in agro-industries and agribusiness for value-addition; and the potential for agribusiness development to provide much needed support services.

Yet for agribusiness, especially agroindustries, to flourish, addressing the growing lack of connection between SSA's agriculture and farmers and the market, particularly at subregional and regional levels is crucial. This includes strengthening both backward (from input markets) and forward (from output markets) disconnects. Amidst this disconnect is a paradox with regard to SSA trade and marketing: SSA has continued to open its markets to traders outside the continent in response to calls for global trade liberalization, but has remained largely closed to intra-African trade. As a result, the potential for intra-African trade within and between subregions is largely untapped. While traders from outside the continent have continued to visualize a continent-wide market, there seem to be asymmetries in the perceptions of market and investment opportunities by private agroindustry and agribusiness communities. Most of them perceive a national, or at best, a subregional market, not a common regional market. In the face of globalization, this limited scale is not optimal. Economies of scale along commodity value chains, economies of vertical coordination among the different stages and economies of complementary diversification and specialization among countries and subregional groupings are critical in order to realize the full competitiveness gains and the intraregional potential of an African common market in agriculture.

Improve the connection between farmers and markets. The link between producers and post-harvest activities can be improved to increase the efficient use of production and postharvest technologies. Technical assistance in production and postharvesting techniques and operations, and training and capacity development to enhance farmers' management, negotiating and bargaining skills are much needed. Other approaches include the promotion of contract farming/outgrower schemes or other forms of contracts that allow for advance payment and provision of inputs and extension services from agribusiness companies to farmers, thereby reducing the need for credit to which many farmers lack access. Farmers will also benefit from innovative methods of receiving market information and intelligence, mechanisms and guidelines that allow for accreditation of agribusiness companies, farmers organizations and cooperatives, as well as regulations on foreign investment.

Capacity development and facilitation of dialogue between farmers, distributors, agroprocessors and marketing agents. This approach can be used to improve adherence to standards relating to quality and volume, as well as timeliness in the delivery of agricultural produce. Productive dialogue is key to examining agribusiness companies' pricing incentives with a view to encourage farmers to produce higher quality products in a timely manner. In addition, establishing long-term contracts and viable partnerships between farmers and agribusiness companies that ensure the provision of training, technical, extension and financial support to farmers and farmer organizations has proven to be fruitful.

Other options for improving connections between farmers and markets include increasing and sustaining government/public sector support to develop and implement policies and guidelines that encourage investments in private agribusiness ventures while protecting producers; facilitate information generation on production and post-production technologies; provide marketing infrastructure and information systems; and put in place fiscal incentives that are supportive of research and development not only for enhancing on-farm productivity, but product development based research and innovation to facilitate off-farm growth of agro-industries and marketing.

Market development and market access. The state of underdevelopment in SSA markets, low levels of market integration and poor infrastructure continue to cripple the competitiveness of African agriculture. Africans, the majority of whom live in rural areas, are poorly served by both input and output markets. Without well functioning input markets, developments in AKST will not benefit SSA farmers, as seeds, fertilizers, tools and other inputs will remain out of reach for the majority, due to high input prices resulting from inefficiencies created by high transaction costs and information asymmetry. Similarly, low prices in output markets prevent producers from earning income conducive to poverty alleviation and stimulating a demand for non-farm products, a necessary condition for industrial growth and a structural transformation of SSA economies. Improving the functioning of SSA markets is vital to reversing the stagnant state of agricultural productivity and to increasing incomes in the largest employment sector on the continent. In addition to increasing incomes for the poor, well functioning markets can reduce the food bill of urban populations, the majority of whom are food insecure and spending a large proportion of their incomes on food.

Interventions for enhancing the performance of African markets and hence linking producers to the markets must ensure that markets work for the poor, by developing markets where markets do not exist and improving infrastructure where markets do not function properly due to infrastructural related constraints (MA, 2005). Markets are especially rudimentary in environments characterized by low population density, dispersed rural households and a poor rural roads network. In addition to ensuring that markets exist and function, addressing challenges related to market exclusion for the poor is crucial. These constraints include inadequate productive assets and collateral; social attitudes barring women from participating in the market; and poor legal and regulatory environments. Even where markets exist and efforts have been made to provide the poor with the tools necessary for participating in them, unfavorable terms of trade including poor output prices and wages remain major challenges to the performance of SSA markets. The situation is exacerbated by a lack of bargaining power by the poor and poor access to information. Some options for addressing these challenges are offered below.

Improving basic infrastructure. African trade and marketing is constrained by the rudimentary state of Africa's infrastructure. More innovative approaches are necessary to create, through policy, legal and institutional reforms, an incentive environment that is conducive to mobilization of initiatives and resources from rural communities, farmers' associations and other private-sector stakeholders for investment in basic production, market and social infrastructure (e.g., irrigation, rural roads, rural water supply and electricity systems, health and education facilities). African governments must be encouraged and supported to develop national policy frameworks that identify priorities for rural investments as part of a national network of services and infrastructure, and specify the roles and responsibilities of various actors in delivering services. With decentralization taking root in many Africa countries' governance structures, it is vital to encourage greater involvement of decentralized rural communities in direct investment and maintenance of roads. The value of increasing the density of rural and feeder road networks cannot be underestimated. Lessons must be drawn on innovate public-private partnership (e.g., through taxation and public financing) for feasible domestic action in this regard.

Improving the performance of domestic markets. This calls for an understanding of current realities and future trends in the structure and magnitude of effective demand for agricultural products. In this regard, African governments must intensify and complete agricultural policy reforms and market restructuring processes, most of which are underway with a view to putting in place institutional, legal and financial frameworks that promote private investment in agribusiness and agro-industrial enterprises. It would be practical to put emphasis on small-scale industries, capable of diversifying food and agricultural products, supplying effectively agricultural inputs, and providing basic transport and marketing services. Responding to consumers and other marketing agents requires the enactment of appropriate regulations on product standards to improve the quality and increase the competitiveness of food and agricultural products.

Viable strategies to promote the development of strong and effective market information systems would help to complement other strategies to facilitate market access, including the provision of financial support and the mobilization of private participation for strengthening national market information collection systems. Africa must take advantage of ICT to put in place functional subregional and regional networks of Agricultural Market Information Systems (AMIS).

Regional integration to facilitate intra-African trade. The potential benefits of regional integration in Africa have been accepted by African governments as demonstrated in their adoption of the Lagos Plan of Action in 1980 at the OAU Extraordinary Summit. The Lagos Plan of Action highlighted the goal of regional integration, which was further concretized in the signing of the Abuja Treaty, establishing the African Economic Community (AEC) in 1991 and ratified in 1994. The Abuja Treaty outlined a gradual process for establishing regional economic communities (RECs) to act as the building blocs for the AEC as follows: AMU (The Arab Magreb Union), ECCAS (Economic Community of Central African States), COMESA (Common Market for Eastern and Southern Africa) SADC (Southern African Development Community) and ECOWAS (Economic Community of West Africa). The Treaty envisaged a process that would culminate in the establishment of the AEC by 2008, including the strengthening of the RECs, removal of tariff and non-tariff barriers, the establishment of free-trade areas and the formation of an African common market. African governments, by signing the treaty, committed to promoting the integration of production structures, processing, trade and marketing systems in order to speed up agricultural development and food production. A renewed commitment by African States under NEPAD and trends toward strengthening regional integration under the existing subregional commissions are a welcome sign, but more needs to be done to ensure a successful integration of Africa's market. Some alternative adaptations include implementing existing regional integration agreements and targets set within each agreement; improving procedures for customs and harmonizing national taxation and support policies for more efficient cross-border trade; creating, through public-private partnerships, subregional marketing mechanisms and institutions to develop marketing strategies for African products; removing infrastructural and institutional barriers (both legal and illegal) to investment promotion and free movement of commodities across borders; and rationalization of the regional economic communities.

Current efforts are being made by the African Union (AU), Economic Commission for Africa (ECA) and African Development Bank (ADB) to assist in the rationalization of the Regional Economic Communities. It would be useful for the three continental institutions to also support these efforts by putting in place a mechanism for peer review and learning, as well as monitoring the implementation of various commitments with regard to market integration, within the framework of the African Peer Review Mechanism.

Increasing access to global markets. Improving the access of Africa's agricultural products to global market calls for action at the national and subregional levels. Capacity for policy research on the impact and implications of the various requirements of WTO agreements for African agriculture could be strengthened to provide vital information for African trade negotiators. To better meet WTO requirements and the needs of African countries, the establishment of technical committees (or standards bureaus) involving key stakeholders would be helpful for the development of appropriate regional and international product standards and technology regulations. With current trends in globalization and trade liberalization increasing the demand for high quality standards, the selection of appropriate means (technical seminars, training workshops, ICT, extension networks, etc.) for informing and educating farmers and private agribusiness entrepreneurs on acceptable product standards becomes important. At the global level, African governments could benefit from high-level forums (e.g., ministerial workshops) in which African countries collectively develop capacity to engage in multilateral trade negotiations, including phytosanitary and other agricultural trade regulations. This can be done under the aegis of AU and with support from the ECA and ADB. In such a case, OECD policies regarding subsidies and market access, which constrain trade opportunities for major agricultural commodities and products from Africa, would likely become prominent issues.

5.4 Enhancing the Contribution of Women to Agriculture

Women account for approximately 70% of agricultural workers and 80% of food processors in SSA; they are more likely than men to be managers of natural resources and often maintain and share traditional practices. Yet women typically are disadvantaged relative to men in terms of access to education, extension services, credit (due in part to women's higher illiteracy rates), irrigation and land ownership rights. Moreover, women are poorly represented in the supply of AKST, whether as researchers or extension agents—for example, in 2000, just 18% of African agricultural researchers in a 27-country sample were female (Beintema and Stads, 2006).

The gap between the importance of women in agricultural production and processing and their weak representation in and access to agricultural services suggests that there is scope for enhancing their contribution to the agricultural sector. Improving women's general education has been shown to have a positive impact on agricultural yields. In countries where modern agricultural technologies have been introduced, returns on an additional year of women's education range from 2% to 15%, more than the returns for the same educational investment in men. Further, policy experiments in Kenya have suggested that primary schooling for women agricultural workers raises their agricultural yields by as much as 24% (Table 5-1).

Though it has not been proven, increasing the proportion of women extension agents is likely to increase the number of women attending extension meetings and talking with extension agents and increase the relevance of AKST for women. Extension officials are typically men (only 17% of extension agents in SSA are women) and, depending on particular country and regional norms, may not be able to, or may choose not to speak to women farmers (Das, 1995).

In much of SSA women have "secondary" rights to land, obtained through their husbands or other male kinsfolk (Toulmin and Quan, 2000). They often have access to their own plots of land, which may be of a lower quality than those available to men, on which they may cultivate different crops than their husbands. The extent to which women are less likely than their husbands or other male farmers to invest in their plots differs from country to country. For example, women's level of inputs in Burkina Faso has been found to be similar to men's, but in Uganda women are less likely to plant trees and make other long-term investments in productive assets because they are not confident of being able to control any ensuing profits (Toulmin and Quan, 2000). Hence the likely impact on agricultural production, particularly long-term investments, of more formalized access to land for women will vary from country to country.

Women's access to land and their degree of land tenure security on private and communal lands can be improved through the implementation of land policies and laws oriented towards equal rights for men and women. Although many countries are at an advanced stage in the formulation of gender sensitive policies, laws, and other instruments, implementation is slow (e.g., women received only 20% of land under the recent Zimbabwe land reforms). To catalyze implementation, reforms can be accompanied by mechanisms such as the harmonization of laws related to inheritance, marriage and property rights. In addition, political will and clear guidelines and benchmarks for monitoring implementation to allow appropriate authorities, including citizens, to hold governments accountable in this regard are more likely to lead to successful implementation of land reforms (see Box 5-2).

Women farmers access only 10% of credit allocated to smallholders and only 1% of available agricultural credit. These data could reflect either a lack of supply of credit to women or a lack of demand. For example, women who feel insecure about their land are less likely to choose to invest in that land and so less likely to demand credit.

Although the following options have not been proven to increase the likelihood of achieving the assessment goals, they can increase the profile of women in agriculture. Quantifying the role and value of women's knowledge and contribution to agriculture and natural resource management, particularly with respect to local and traditional knowledge, can emphasize the importance of women in agriculture and subsequently the cost of not fully mainstreaming them in all aspects of agricultural development.

Protocols that ensure that women are involved in the design and enumeration of any questionnaires and surveys that are undertaken and that women are fully represented in any sample that is taken can be introduced relatively easily and at low cost. Data collection that deals particularly with

Table 5-1. *Contribution of African women to family livelihoods.*

Activity	%
Agricultural workforce	70
Labor for production of food	60-80
Food storage and local transport	80
Processing of foodstuffs	100
Water fetching and fuelwood gathering	90
Hoeing and weeding	90
Harvesting and market activity	60

Source: FAO, 2007b.

Box 5-2. Land policy in Africa: A framework for action.

Under the leadership of the African Union (AU) and in close collaboration with the Economic Commission for Africa (ECA) and the African Development Bank (ADB), the Pan-African land initiative on land policy aims to develop a land policy and land reform framework and guidelines in order to facilitate the formulation and implementation of land policies. The process of developing the framework and guidelines involves a series of sub-regional consultations that will ensure that regional realities and initiatives inform the continental framework. This consultative process, involving key stakeholders in land and natural resource issues, is vital to ensuring the necessary political will to the adoption and implementation of the framework and guidelines. The framework and modalities for its implementation and a mechanism for monitoring are in negotiation among the AU Heads of State, within the NEPAD/APRM framework.

issues of natural resource management can ensure that the role of women is determined explicitly—for example, questions can identify the roles of men and women in different activities and in decision making with respect to agriculture and resource management at the household and village levels. Involving women in enumeration may, in some cultures, make it easier to document fully women's activities with respect to natural resource management. The findings from such studies can be incorporated into university curricula. In particular, agricultural sciences, agricultural economics, and agriculture-oriented sociology courses could include specific modules that address the role and contribution of women with respect to natural resource management and knowledge.

Gender-specific roles and the current status quo in many African countries can hinder the process of mainstreaming women into the above activities. The likelihood of successful mainstreaming can be increased with commitment from government and universities, combined with monitoring and assessing over time the numbers of women applying and being accepted for positions.

Options for mainstreaming women in AKST development include efforts to encourage women to study agricultural science, natural resource management, and forestry at school and university and to include the role of women in agriculture in studies both at primary and university level. Although the costs and returns to these strategies have not been assessed, there is a general consensus that better mainstreaming of women throughout education, training and extension is likely to improve the relevance of AKST to women and therefore have a positive impact on the assessment goals.

5.5 Sustainable Use of Land and Water Resources

Africa faces a number of specific challenges with respect to the sustainable use of its natural resource base. These include the increasing degradation of natural resources due to inappropriate resource use, increased competition for resources, climate change, and the loss of agricultural biodiversity including animal genetic diversity. These challenges are exacerbated by the low commitment to integrating environmental concerns into AKST-related strategies; the low capacity for the development of AKST to address natural resource issues; and the low support for women in the management of natural resources.

Addressing the enhancement and sustainability of the natural environment through AKST is particularly challenging in SSA. The emphasis for agriculture in the region has been to increase crop production and reduce malnutrition through arable land expansion and increased cropping intensity. This pressure to increase output will continue over the next 50 years given the continuing chronic malnutrition and low incomes within the region. Most of the increased food production in SSA has been in expansion of agricultural land area thereby putting pressure on marginal land and the non-farm natural resource base outside of the farm (FAO, 1996). These pressures will be reduced if agricultural productivity increases on existing arable land. However, increasing cropping intensity will put more pressure on on-farm natural resources, particularly soils.

Complex biological interactions exist between different resources such as soils and water, suggesting that integrated solutions are required. NRM practices are typically more knowledge intensive than agricultural production technologies, which often embody the technology in inputs such as seeds or chemicals (Barrett et al., 2002). Local and traditional knowledge about the environment is embedded in languages that are typically not formally used in extension (except ad hoc in the field) or in research, except to mine information. This hinders the ability to leverage local knowledge and link it with exogenous AKST.

Problems associated with missing markets (externalities) and common pool resources are common. The actions of an individual farmer with respect to the resources on her farm, for example, may have a negative impact (externality) on resources outside of her farm that she does not take into account in making decisions. Individual farmers' incentives therefore may not align with sustainable farming activities at the community level and so incentives and institutions are required to ensure the resource base is managed sustainably.

If farmers do not see direct benefits to themselves from natural resource management activities, they have little incentive to adopt the technologies (Dejene, 2003). When environmental degradation is gradual it may not be noticeable for several years or more (though soil erosion can occur in less than an hour). Solutions may have high upfront costs but take time to have an impact and so may not be compatible with resource-poor farmers with high discount rates.

Private enterprises may not have a "long-term interest in creating the type of long-term, strategic, public goods research products that are required to ensure a continuous stream of benefits from natural resources to society at large" (Ashby, 2001) and little interest in issues such as water conservation (Scoones, 2005). Whereas the private sector lacks incentives, the public sector lacks capacity (Scoones, 2005), suggesting potential for private-public partnerships. Finally, the natural biological and institutional linkages among resources and resource users are often in contrast to the lack of appropriate organizational linkages among different government ministries and research organizations that would improve the likelihood of environmental degradation being tackled effectively. Particularly in SSA, providing technical solutions to environmental degradation is therefore far from sufficient.

5.5.1 Land: Limiting conditions and available alternatives

Land degradation, and poor soil fertility in particular, is widely accepted as the most critical factor in limiting agricultural production in SSA (Stoorvogel and Smaling, 1990; Smaling et al., 1997; Hilhorst and Muchena, 2000; Baijukya, 2004). The natural resource base in SSA is in many areas highly degraded, due in part to increased competition for resources, inappropriate pricing of those resources, and—increasingly—climate change. There are numerous estimates of the costs of this degradation—irrigated lands 7% below their potential productivity, rain-fed crop lands 14% below, and rangelands 45% below (Donovan and Casey, 1998), resulting in, for example, an estimated cumulative productivity loss over the past 50 years of 13% for cropland (Scherr, 1999).

Increasing degradation of natural resources is already having a negative feedback effect, reducing the potential of agriculture and any new innovations, and making the task of increasing productivity and reducing malnutrition all the harder. For example, soil degradation reduces the potential of agricultural initiatives such as improved water management (IAC, 2004). Current policies and priorities have not, in the main, slowed down this degradation. And despite the existence of many technologies for the improved management of soil fertility in SSA, there has been a poor uptake of these existing technologies by smallholder farmers.

Though contentious, increased applications of synthetic fertilizers are seen by many practitioners as essential for SSA, as reflected in the resolution by AU members to increase fertilizer use significantly by reducing its cost through national and regional level procurement, harmonization of taxes and regulations, the elimination of taxes and tariffs, output market incentives, and access to credit from input suppliers (Chude, 2007). The AU's recommendation to remove all taxes and tariffs from fertilizer and fertilizer raw materials could increase fertilizer use. However, farmers are unlikely to increase their use unless they have access to markets for the output, they are confident that the expected returns are sufficiently high to justify the cost, they have access to affordable credit to purchase fertilizer and the risks of crop loss (or revenue loss from adverse market conditions) are sufficiently low.

Recommendations for fertilizer use typically involve unsophisticated "blanket high dose" applications while research focuses on fine-tuning high-input recommendations that are particularly inappropriate for the region, given the cost of fertilizer in SSA and the understanding that higher doses of fertilizer are more likely to result in environmental pollution (Snapp et al., 2003). More appropriate, particularly for resource-poor farmers in SSA, are approaches and recommendations that enable farmers to maximize returns from smaller input purchases (Snapp et al, 2003). Further, as the following discussion on integrated approaches to water and soil management highlights, given the poor state of soils in much of SSA, mineral fertilizer alone may have little impact on yields and therefore the economic justification for increasing fertilizer use.

Pollution and health hazards from agrochemical use including fertilizer and pesticides in SSA are currently less of an issue than in other regions because most farmers cannot afford to apply any, let alone high levels of fertilizer, particularly given its relatively high cost. However, experience from other regions suggests that in parallel with encouraging increased fertilizer use, efforts will be needed to reduce the negative associated health and environmental impacts including soil acidification and water pollution that particularly come from excessively high levels of fertilizer (Weight and Kelly, 1998). Farmers are more likely to minimize the negative environmental effects of fertilizer use if they have access to technologies that enable technically efficient application, typically specific to local soil conditions (Weight and Kelly, 1998). Biological control is an option for integrated pest management and involves augmentation or conservation of local, or introduced natural enemies to pest populations. There are several examples of where staple and important crops have been saved by biological control over wide areas.

Fifty-seven percent of SSA's land is "marginally sustainable", meaning poorly buffered soils with very low soil organic matter and poor water retention (Weight and Kelly, 1998). Addressing one of these problems without addressing the other in parallel is likely to have very little impact on output, and indeed there is a growing consensus that gains in productivity in SSA require an integrated approach to soil, nutrient, and water management rather than undertaking separate research. On farms with low soil moisture and low fertilizer-use efficiency, the addition of chemical fertilizer is likely only to be profitable where there is regular rainfall or irrigation, and already relatively high organic matter in the soil (Masters, 2002). A combination of organic and inorganic sources of nutrients—integrated nutrient management—has been found in many situations to be more effective than using just one approach (Murwira and Kirchmann, 1993; Swift et al., 1994; Ahmed and Sanders, 1998; Bationo et al., 1998; Murwira et al., 2002; Ahmed et al., 2000). Green manure crops can be grown in farmers' own fields, and there is evidence in West Africa that they can help to revive degraded lands. Yet although green manure technologies have been successfully developed for west Africa, and even though some farmers have adopted them, many farmers see green manure crops as competing with edible and cash crops, and having little observable impact on yields and soil fertility in the short term, and so are reluctant to adopt them.

In some areas of SSA, such as western Kenya, phosphorus deficiency is a critical limiting factor for crop yields, such that without application of phosphorus, investments in nitrogen or nitrogen-fixing legumes has little impact (Sanchez, 2002; Smalberger et al., 2006). Phosphorus can be added in several ways: phosphorus fertilizers; phosphate rock (such as Minjingu rock in Kenya); and phosphate released from biomass such as from Tithonia leaves. Phosphorus fertilizers are relatively costly in SSA and are scarce in some countries, due in part to poorly developed markets, a lack of domestic production, or limited foreign exchange, and so, not surprisingly, phosphorus application in SSA is low (1kg ha^{-1} compared with 14.3 kg ha^{-1} in Asia) (Bruinsma, 2003; Smalberger et al., 2006). The use of relatively small applications of phosphorous has been found to be effective at increasing vegetative cover in Nigeria (CGIAR). However, in water excessive phosphorous can over-stimulate the growth of algae thereby depleting the water of dissolved oxygen and harming aquatic life. The addition of phosphorous combined with improved soil erosion management techniques is likely to reduce the potential negative externalities of its application. Further, phosphorous fertilizers may contain cadmium which can enter certain crops including potatoes and leafy vegetables and which is toxic to humans.

Integrating Approaches

Encouraging more integration requires alternative approaches to the "transfer of technology" model that has been common in SSA. There has been criticism of natural resource related research approaches that are predominantly undertaken on research stations rather than collaboratively on farmers' fields. For example, most information on the contribution of legume nitrogen is from research stations where soils have sufficient P and other nutrients and is sometimes is irrigated (Mafongoya et al., 2006). Most soil fertility research in East Africa has concentrated on recommendations for monocrop systems despite the fact that most smallholder farmers use intercropping and mixed cropping systems (Bekunda et al., 2004). Evidence suggests that involving farmers in soil fertility research improves the likelihood of recommendations that are more relevant to farmers' situations (CIAT, 2002; Bekunda et al., 2004). On-farm experiments are more likely to provide realistic rates of return to different technologies and therefore those that would best suit the farmers; and farmers may be more likely than on-station researchers to identify green manures with food or forage uses that are more likely to be adopted.

A number of approaches naturally lend themselves to farmer-oriented research. Production ecological approaches and conservation farming have both been promoted as approaches to reversing on-farm environmental degradation that take account of soil-water-nutrient interlinkages. A production ecological approach is one way to take account of complex biological linkages such as those between water retention and soil fertility, and between pest management and soil fertility. It requires an understanding of what is happening in the fields to orient research towards technologies that enhance productivity and profitability in an environmentally sustainable way. For example, integrated soil management requires a combination of improved soil hydraulic measures, organic fertility maintenance, and inorganic fertilizer and soil amendments (Batjes, 2001).

Conservation tillage (in which crops are grown with minimal cultivation of the soil) directly affects water infiltration and water retention in the soil, and so improves the efficiency of rainwater use, and may contribute to yield stability and food security in drought prone regions. However, more studies of sufficient size are required to determine the true benefits and constraints to the adoption of conservation farming. For example, conservation tillage has high labor requirements that may deter farmers from adopting the approach. The effectiveness of conservation tillage most likely depends on specific agroclimatic conditions—for water-conserving conservation tillage—and access to draft power influences profitability (and hence the likelihood of uptake). Moreover, the benefits of conservation tillage occur gradually over time, suggesting that poor credit-constrained and risk-averse farmers (a typical SSA farmer) will find it difficult to adopt such techniques without confidence as to their benefits and the ability to make upfront investments—such as through access to credit.

Currently the capacity for integrated soil fertility management in many countries in SSA is limited by insufficient numbers of professional personnel and the essential laboratory facilities required (World Bank, 2002). More integrated approaches require interdisciplinary teams working together, more complex institutional arrangements, and increased coordination among different agencies and organizations, particularly given that governments often separate, for example, agriculture, natural resources, and wildlife agencies. Integrated approaches may also imply new approaches to training and extension. Previously, efforts to undertake research at the level of large complex systems have tended to result in excess amounts of costly effort to collect data, yielding few results that are of immediate practical value (Campbell and Sayer, 2003).

Livestock. The role of livestock in land degradation has been controversial: Livestock grazing and pastoralism in SSA have often been viewed as a critical factor in the interaction between agriculture and the natural resource base, and overstocking has long been blamed for the cause of extensive land degradation in rangeland areas. For example, some state that overgrazing causes 49% of soil degradation in dryland SSA, while agriculture causes 24%, and overexploitation and forest degradation 27% (Dejene et al., 1997). Many previously proposed solutions to perceived overstocking are now considered to have been misguided. For example, in Tanzania, officials have viewed large herd size and overgrazing as major causes of land degradation and so attempted to enforce destocking and also introduced zero-grazing of improved dairy cows for milk. Yet livestock were moved to other areas (rather than numbers being reduced), thereby transferring the problem to different locations and also leading to increased malnutrition (Dejene et al., 1997). A lack of understanding of the social, cultural and economic roles of livestock most likely led to misguided solutions that did not have the intended effect and had overall negative consequences (Box 5-3).

There is increasing evidence that climate, rather than overgrazing, is the key cause of land degradation in rangelands. Climate change is likely therefore to exacerbate the problem of land degradation. For example, long-term monitoring by ILRI (International Livestock Research Institute) in East and West Africa has provided evidence that climate has been the main determinant of changes in arid and semi-arid environments and that rangelands are resilient and capable of recovery. Indeed, strong seasonality of rangeland production in the Sahel appears to limit the environmental damage of overgrazing to short periods and confined areas (Ellis, 1992; Hiernaux, 1993).

Recent rethinking of "range ecology" suggests that the opportunistic range land management practiced by pastoral livestock farmers is indeed the appropriate response to natural conditions (Behnke et al., 1993; Scoones, 1995; Homann and Rischkowsky, 2001). Local and traditional management strategies have evolved naturally in response to knowledge of the spatial and temporal availability of natural resources, "and include mobile resource exploitation, flexible stocking rates, and herd diversification, sustained by a system of communal resource tenure" (Sandford, 1983). These strategies, however, may not be able to evolve as rapidly as needed given changing climatic conditions. Nonetheless, they can be integrated into AKST research and development if they are first documented and understood within pastoral livelihood constraints (Oba and Kotile, 2001).

In general, there is insufficient understanding of the role of livestock in livelihoods and the motivations behind pastoralist practices. Better knowledge can be incorporated into the development of technologies and approaches that enable pastoralists to manage their resource base more effectively. For example, approaches that simply encourage lower stock levels may not be sufficient, in part because of farmers' and

Box 5-3. Traditional pastoralist approaches to managing grazing lands.

"A classic example of a paradigm shift lies in the history of the management of African pastoral systems (Ellis and Swift, 1988). Recommended methods of reducing overgrazing in these pastoral systems included group ranches, grazing blocks, and associations in which pastoralists were confined to particular tracts of land to better regulate the interaction between animals and plants and raise productivity. Over time, these new management methods were found to destabilize grazing systems that are characterized by intra-annual variability resulting from frequent drought. In contrast, pastoralists using traditional methods cope with multiyear drought by dispersing into small herds and groups over a wider area, thus expanding the spatial scale of exploitation. In nondrought periods, pastoralists ensure that unused space or an ungrazed reserve is available for periods of drought by stocking some areas in the ecosystem well below their average carrying capacity (undergrazing) while overgrazing others. This stabilizing mechanism relies on mobility, whereas the modern management strategy is based on confinement. In other words, recommendations that do not factor in variability and disturbance in the ecosystem often lead to long-term failure. Research had to define alternatives to conventional management of grazing systems that functioned at the ecosystem level, took into account hierarchies of interdependent subsystems, and were effective over the long term. Technical packages designed for a reduced spatial scale and short time horizon could not cope with the variability in the system, and indeed became associated with increased degradation in the long run". (Ellis and Swift, 1988)

Source: Ashby, 2001.

pastoralists' reasons for keeping livestock, and in part because of the role of climate. Similarly, rangeland degradation is unlikely to be addressed effectively unless the underlying motivations for environmentally destructive practices are understood. For example, the use of fire is widespread as many livestock owners consider it the best means of reducing the incidence of livestock disease, encouraging regeneration of grass and pasture for livestock, and clearing new land. However, the use of fire has negative environmental effects that include the destruction of vegetation cover and soil organic matter, lowering the diversity of soil fauna, and increasing erosion. AKST efforts that address livestock diseases could, under these circumstances, help to reduce environmental destruction by reducing deliberately started fires. These findings are an example of how understanding the motivations behind livestock owners' actions and integrating this knowledge into AKST development can help lead to identifying the causes (disease) of environmentally destructive actions rather than dealing with the symptoms (burning).

Developing ways of conducting more research in pastoralists' native languages using participatory methods can present opportunities for achieving better understanding of the above-mentioned subjects. Herders generally understand well the environment, their animals, and strategies for survival and production. A substantial challenge exists in developing (or matching) terminologies for exogenous AKST, animal science and range management concepts, not to mention educating outside researchers in the languages. There is, therefore, the potential for combining knowledge and generating new understandings in the vernaculars of the people most directly involved in this mode of production.

Pastoralists' use of rangeland is often more conducive to conserving wildlife than more intensive alternative land uses. However, there is a natural tension and therefore conflict between pastoralist land management techniques and wildlife needs. Given the growing importance of nature-based tourism in many SSA countries, particularly in east and southern Africa, there are likely to be increased economic benefits from supporting the dual use of rangelands.

5.5.2 Water: Limiting conditions and available alternatives

Under drought conditions, risk-averse farmers tend to adopt low external inputs crop production systems rather than high yielding technologies and management practices. AKST has a direct role in terms of the development and adaptation of new technologies for more efficient water use. There is scope for improved irrigation techniques, water harvesting technologies, and developing approaches for using water more efficiently in rainfed areas. Improved water efficiency of crops can also be embodied in seeds—in particular through drought-resistant seed varieties.

Drought-resistant species will be increasingly important in SSA, especially for regions that are negatively affected by global warming and climate change—rainfall and higher temperatures are predicted to be particularly problematic for southern Africa. A key question is whether these drought-resistant species will be developed by the private sector, and whether they will be cost effective for small-scale and poor farmers, or whether such species will be prioritized sufficiently in the international research centers. There are examples of drought-resistant species that have been successfully developed, such as open pollinated maize, a result of intensive breeding efforts between the international center CIMMYT and national researchers (Scoones, 2005). Such a development required long-term funding and research commitment within the public sector.

Technologies for increased water productivity exist for both rainfed and irrigated systems, including water harvesting and drip irrigation, which have been shown to be technically effective. Advances in AKST offer low cost technologies that can reduce the uncertainty farmers face.

Despite scope for considerable increases in irrigation, there is strong support for a focus on integrated rainwater management and improved understanding of farmers' motivations and ability to adopt the requisite technology. An alternative to large-scale irrigation projects that is particularly relevant for resource-poor farmers is the promotion of rainwater harvesting. Water harvesting can reduce risk by 20-50%. Once output risk is reduced, farmers are more likely to adopt improved seeds and high yield varieties, and apply more fertilizer and manure. Many farmers could benefit from these technologies, no major infrastructural development is needed, and the benefits are more equitable than large-scale irrigation projects. One possible drawback of these approaches is that they often have a high labor demand and that may deter adoption particularly where HIV/AIDS rates are high.

In SSA, unlike most other regions, water resources typically are not over-exploited (a key exception being South Africa). Most countries have enough water to meet their near-future needs—though these resources are often as yet untapped. Yet, though there is considerable scope for increased exploitation, most countries in SSA are not currently making the necessary investments to exploit the water resources (Molden and de Fraiture, 2004). Therefore an immediate challenge for many countries in SSA is to exploit the existing water resources more fully. Water scarcity is likely to become a much larger issue in the future, and is already causing localized conflicts in some countries (for example, the Ewaso Ng'Iro North Basin in Kenya) (Weismann, 2000) and so mechanisms are required to ensure that water exploitation is technically and economically efficient and that equitable access to water resources is taken into account.

Irrigation. In the past, there was a considerable focus of AKST on the use of large-scale irrigation for agricultural systems. Although such irrigation systems can have a positive impact on poverty reduction, they have at the same time often proven incompatible with environmental concerns where water off-take for agriculture has a negative impact on water-related ecosystems and ecosystem services. Moreover, research from Asia suggests that research into rainfed areas offers greater productivity increases and greater reductions in poverty than similar investments in irrigated agriculture (Fan et al., 2000a,b; Bindraban and Rabbinge, 2003).

Therefore, the potential for irrigation needs to be considered in the context of alternative water management strategies, external costs imposed by an irrigation scheme and distributional considerations. Investment in irrigation requires coordination among a number of farmers and significant upfront funds. NEPAD proposes that countries set up public-private partnerships for managing basic irrigation infrastructure, and encourage the private sector to invest in irrigated agriculture in parallel. These investments are only likely to occur however if the legal framework is sufficiently transparent and credible for the private sector to be willing to make long-term investments.

Water resources in SSA have typically been managed within administrative boundaries. A more logical approach is for water resources to be managed within the boundaries of a river basin (UNEP, 1999). Such an approach requires institution building and sharing of information. Further, organizational structures most likely will need to be adapted to reflect realities such as the increasingly artificial divide between rainfed and irrigated agriculture (Molden and de Fraiture, 2004). The development of water-harvesting techniques and small-scale irrigation are likely to be hindered by the current sectoral distinction between rain fed and irrigated agriculture, reinforced by the current professional divide between, for example, agronomists who work on rain-fed agriculture and irrigation engineers (Molden and de Fraiture, 2004), and institutional divide—these two areas typically fall under different government ministries. Either new explicit institutional linkages are required, or the merging of responsibilities within one particular ministry. In parallel, those involved with separate research into rainfed or irrigated agriculture can be provided with opportunities to work more closely both with villagers and each other.

5.5.3 Incentives and motivation for change

Farmers and researchers rarely consider fully the costs of environmental degradation. Farmers themselves may not be sufficiently aware of the costs on their own farms, or the damage that they are causing occurs on land other than their own and they do not bear the costs. In Cameroon many farmers do not regard soil fertility as a problem (despite a general consensus that in west Africa soil degradation is the biggest problem for the sustainability of agriculture), in part because there are still opportunities for more extensive slash and burn agriculture (Sanchez, 2000). Similarly, researchers developing new approaches to crop intensification or pest management, for example, may not take into account environmental costs, as these may be cumulative over time, external to the individual farmer, or resources may be priced at below their "social cost" (subsidized water and electricity).

Ultimately, farmers are more likely to undertake long-term investments in improving the resource base on their farms if they face the true cost of any environmentally destructive practice (polluter pays principle), if they produce cash crops and have good access to markets for outputs and inputs, access to credit, and access to extension services (Reardon et al., 1995). Machakos, Kenya is a much cited example of an area where land degradation has been reversed and agricultural production increased despite increases in population. Factors that contributed to this success include good transport infrastructure to markets, secure land tenure and above average rural education and health (Toure and Noor, 2001).

Unless the full costs of environmental degradation and resource exploitation to farmers themselves (on-farm degradation), to the community (degradation of common pool resources such as forests), or to other sectors (pollution of down-stream water supplies) are quantified (both for current practices and proposed new practices) it will be difficult to persuade policy makers or farmers to adopt technologies and approaches that reduce the degradation.

The enabling and institutional environment is particularly important with respect to increased water exploitation. For farmers to choose to adopt efficient water techniques, not only must they be affordable for farmers, but appropriate institutions and incentives need to be in place, and farmer motivations and the links between water use and soil fertility better understood.

In the long run, realigning farmers' incentives over their water use is essential for improving water efficiency and water equity. This entails appropriate mechanisms for allocating water—whether pricing, allocation of property rights, regulation, social pressure, or negotiation. The appropriate approach in a particular country will depend in part on existing institutions, the ability to enforce rights through formal systems, and social cohesion within a particular area. Market mechanisms are one approach to improving the efficiency of resource use by ensuring that users pay the true cost of their actions (making the polluter pay; charging for water taken from rivers or aquifers). However, given that many farmers in Africa are poor, there are considerable equity issues to be considered. Further, the costs of establishing and monitoring such market institutions could be high. Ensuring the appropriate institutions also entails ensuring that farmers are able and willing to choose water-efficient technologies and drought-resistant plants. Hence issues of risk and risk aversion, and access to credit are relevant.

A key problem to tackle with respect to improving water efficiency in agriculture is that typically individual farmers do not currently bear the true costs of the water that they use (many of these costs are externalities to the farmers), whether in terms of resulting downstream pollution, or in terms of taking water away from other more socially efficient uses. When water is relatively readily available this is not a problem. However, all forecasts are that water scarcity will become an issue in SSA in the future.

There is a natural tension between water for agriculture and water for ecosystem services. For example, farmers taking upstream water may harm downstream ecosystems. If water is free at the point of access, farmers can pump water from an underground aquifer or divert water from a river without paying for the water and will typically use more water than is socially efficient because they do not have to bear the costs of the water use. Moreover, farmers will likely not have an incentive to adopt relatively costly but efficient drip irrigation or water-harvesting techniques. In these circumstances efforts to increase productivity through the greater exploitation of water may be at odds with the assessment goals with respect to ecosystems and biodiversity. Yet more efficient water use requires markets other than those for water to function efficiently. For example, farmers may need access to credit to afford more efficient water-harvesting and water-use technologies, access to insurance if they are exposed to higher risk, or better access to markets given expected increased outputs and higher input costs. South Africa has explicitly addressed the problem of competing claims for water between agriculture, industry, human use and ecosystems by introducing a "reserve for the environment" in the 1998 National Water Act that reduces available water for other uses by 15-20% (Inocencio et al., 2003).

Typically in SSA there are few formal mechanisms for allocating water efficiently among different users and needs, though local and traditional mechanisms naturally tend to develop, at least among farmers, as water scarcity increases in the absence of formal rules. If these local mechanisms are ignored, the likely result will be conflict and a reduced likelihood of any new initiatives working. For example, in Tanzania there has been a focus on the use of the statutory legal system to allocate water that ignores the plurality of systems operating in the country and the prevalence of customary arrangements, which has resulted in conflicts between traditional water users and new water regulations (Maganga et al., 2004).

Approaches to "internalizing the externalities" associated with water use include pricing (such that the price reflects the marginal benefits to different users—though tricky to implement, even in richer countries), regulation (such as assessing and regulating environmental flow requirements to sustain specific ecosystems and the services that they provide), allocation of property rights enabling private markets to develop, and negotiation. Without changes in the current system (water typically being free at the point of access for those with de facto access rights), the appropriate incentives for farmers to adopt more efficient water technologies will not be in place, and water will continue to be used inefficiently. That is, getting the regulatory and institutional environment right is critical before attempting to introduce new technologies. There are also equity considerations—poorer households may simply not be able to afford water if it is priced at its true cost.

5.5.3.1 Fiscal incentives

In South Africa, the 1998 National Water Act attempts to balance efficient and equitable water allocation using what is termed a pro-poor "some for all" approach. Improving the productivity of water use in the agricultural sector—the biggest user of water—was seen to determine the extent to which the efficiency, equity, and sustainability objectives could be reached (Kamara and Sally, 2004). In 2000 the government decided that households would receive 6000 liters per month free. Remaining water would be allocated to domestic uses such as small-holder livestock and small-scale gardening. After these needs were fulfilled, compulsory licensing was introduced to allocate water among other needs including larger-scale agriculture and forestry. Further, rather than considering conventional measures of agricultural water productivity such as "crop per drop" or "monetary value per crop", other measures are included such as "jobs per drop" (Kamara and Sally, 2004) (Box 5-4).

Whether pricing, regulation, property rights, or negotiation is chosen as a route to allocating water in a more efficient (and possibly equitable) way, a better understanding of the value of water for different competing users is required, as is research into new institutions for allocating water more efficiently and thereby creating appropriate incentives for farmers to adopt water-efficient technologies. Most likely this research will recommend changes in access to water, either through pricing or regulation. But it must also link to technology developments such that the conditions for farmers to adopt the technologies are appropriate.

A lack of credit and risk-sharing institutions reduces the likelihood that farmers will adopt technologies that conserve the natural resource base. In SSA rainfall is highly unpredictable, resulting on average in complete crop failure once every ten years in semiarid lands. Farmers are typically unable to insure themselves against the risky environment within which they farm and so would benefit from technologies that reduce the risks of farming such as improved water-harvesting techniques. However, farmers also often lack access to credit to make such investments, and taking on debt also increases their risk. Hence in parallel to introducing new technologies for water management and harvesting, credit, insurance and other risk-sharing institutions would improve the enabling environment for farmers and increase

Box 5-4. Lessons from South Africa.

The 1998 National Water Act in South Africa aimed to reach a balance between efficient and equitable water allocation, using a pro-poor "some for all" approach. Improving the productivity of water use in the agricultural sector—the biggest user of water—was seen to determine the extent to which the efficiency, equity, and sustainability objectives could be reached (Kamara and Sally, 2004). In 2000 the government decided that households would all get a 6000 liter per month allocation free, then water would be allocated to domestic uses such as smallholder livestock and small-scale gardening. After these needs were fulfilled, compulsory licensing was introduced to allocate water among other needs including larger-scale agriculture and forestry. Moreover, rather than considering conventional measures of agricultural water productivity such as "crop per drop" or "monetary value per crop", other measures are included such as "jobs per drop".

Source: Kamara and Sally, 2004.

the likelihood that they would be willing to adopt the new technologies.

Farmers in SSA typically need improved access to credit and microcredit is relatively well established. However, most is provided through NGOs and may not be sustainable without the injection of funds to cover the relatively high administrative costs. Recently, commercial retail banks have become involved by providing capital to organizations at commercial rates that then provide the microcredit directly to farmers. This involvement of commercial banks may offer a more sustainable longer-term route for providing capital for microcredit. Although in the literature there is a focus on microcredit, access to formal credit is and will remain an important issue for larger-scale farms. The use of formal credit requires banks to be willing to supply the credit, which is more likely to occur in an institutional environment where farmers have collateral (such as land or fixed assets), property markets are efficient (such that land and property offered as collateral has sufficient value to the bank), and there is an efficient and effective legal system that enables banks to take action if farmers default.

Weather insurance is mentioned in the literature as a potential mechanism for reducing farmers' financial exposure to highly variable rainfall and hence crop yields. However, problems of moral hazard (farmers may put less effort into their farming activities if they are insured against losses), the difficultly in monitoring farming effort and output, the problem that negative weather shocks to farmers tend to be correlated, and the possible unwillingness of farmers and likely inability of poor farmers to pay the insurance premiums mean that the provision of crop insurance is likely to be limited. So far, weather insurance has not been successful (Dercon et al., 2004). However, some initiatives are being piloted by the World Bank in SSA and Latin America that payout depending on rainfall rather than crop output, thereby eliminating moral hazard (Devereux, 2003). Such insurance may be more relevant to drought than to climate variability, and the problem of covariance remains (if one farmer is negatively affected the likelihood is that most farmers in the locale will be), suggesting that private companies may not be willing to provide such insurance (Devereux, 2003).

5.5.3.2 Land tenure

In many SSA countries, inadequate land tenure structures are perceived to be a major obstacle to sustainable agriculture, rural development, and equitable access to resources. In general, exploitation (and over-exploitation) of natural resources is inextricably linked to the institutions surrounding access to land, pricing, and regulation. Land reform has often been cited as an approach to reducing environmental degradation (in addition to other benefits)—a way of allocating property rights such that individuals internalize the negative impacts of their actions on the environment, so that farmers can access credit for appropriate investments in managing soil and water, and so that farmers have the confidence to make these investments without concern that they will lose access to the land. However, local institutions have evolved in SSA in response to the lack of formal property rights over resources and need to be understood in this context before costly land reform is undertaken.

Long-term investments in natural resource management have been found to be correlated to secure land tenure and short-term investments to insecure tenure, suggesting that formal land titling would benefit the adoption of investments in natural resource management (Gebremedhin and Swinton, 2003). However, land tenure reform alone rarely brings all the hoped for benefits. Land titles have also been shown to have little impact on reducing environmental degradation and there is plenty of evidence in the literature that land titling does not increase credit transactions, improve production, or increase the number of land sales (Seck, 1992; Melmed-Sanjak and Lastarria-Cornhiel, 1998). Indeed, many benefits from land titling appear to be offset by increased risk of small holders losing their land if titled, high transactions costs of titling land, the reality that with or without title, small farmers rarely access formal credit, and that rural land has little value as collateral to financial institutions.

Indeed, it is not necessarily formal land tenure per se that is important for farmers' long-term investments, but whether individual farmers perceive their claims to the land that they are farming to be sufficiently secure to make the required investments. That is, secure land tenure is important for providing an appropriate incentive for farmers to adopt technologies that, for example, enhance natural resources, but this security can be obtained without formal land titles. However, women's weaker rights to land and tenure security do appear as a constraint to meeting sustainability and development goals and more research is needed into how land tenure systems and property rights can be developed that benefit women and minority groups such as pastoralists.

Another impact of formal land titling could be that farmers have an opportunity to consolidate land holdings through buying and selling land, thereby increasing the average size of land holdings. In Tanzania the area of land per household has remained at about 2 ha over the past decade, though the majority of households farm less than two hectares (Nagayets, 2005). In other countries such as Lesotho, D.R. Congo and Ethiopia, the area per household is decreasing (Nagayets, 2005), making it increasingly difficult for individual farm households to commercialize. If land holdings begin to consolidate, understanding and dealing with increased rural unemployment and rural-urban migration will become particularly important.

5.6 Crop and Livestock Diversity

Two types of agricultural biodiversity are identified by the Convention on Biological Diversity (CBD): a managed portion that is manipulated by people for their own needs; and an unmanaged portion such as soil microbes, natural enemies, pollinators and their food plants that supports production (Biodiversity International, 2007). Farmers naturally play a role in conserving agricultural biodiversity, a role that can be exploited and incorporated into more formal conservation approaches. However, there is a general consensus that agricultural intensification has been accompanied by decreasing agricultural biodiversity. Industrialized agriculture has tended to promote a small number of species, and scientific research has typically been focused on these species (FAO, 2002; MA, 2005), resulting in a decline in genetic diversity for agricultural crops.

Genetic erosion of indigenous germplasm for both forage and livestock species is increasing in SSA. This is of particular concern for the region because many countries have a wide range of crops that are considered relatively unimportant on a global level, but are important as local staples (Engels et al., 2002). Further, over 95% of Africa's ruminant population is indigenous, supporting the majority of small-holder rural farmers for whom these genetic resources are critical as a source of food, income and secure form of investment. The causes of this genetic erosion include human population growth, increased pressure for land development, urbanization, climate change and controlled breeding and development of livestock breeds with a narrow genetic base to meet the demands of modern production systems. There also appears to be a loss of local and traditional knowledge concerning species diversity, including loss of local language terms, in part a natural consequence of changes in cropping systems.

There are two key linked responses for conserving agricultural biodiversity, as identified by the Millennium Ecosystem Assessment and recognized elsewhere: in situ conservation (conservation of important genetic resources in wild populations in natural habitats, whether farmer fields or within existing agroecosystems), and ex situ conservation (conservation of genetic resources in off-site gene banks).

5.6.1 Safeguarding and maximizing potential of genetic resources

Changing climatic conditions, the importance of livestock in SSA, clonal propagation and the high costs of ex situ conservation suggest an emphasis on in situ conservation to be most appropriate for SSA. In situ conservation is essential for conserving animal genetic resources, and most relevant for hard to store tropical species and for those that are clonally propagated, and therefore particularly relevant to SSA. It also helps maintain evolutionary processes (preserving the process of crop evolution) and may have a positive impact on equity (Brush, 1992; Jarvis et al., 2000; Meilleur and Hodgkin, 2004; FAO, 2007a).

Although ex situ collections substitute imperfectly for the evolution of crops on farmers' fields, storing genetic resources as back-up seed stocks in ex situ collections is a key element of conserving genetic diversity (Drucker, 2005). However, ex situ collections are costly, involve considerable losses, and—due to climate change or genetic drift—genetic resources held in long-term storage may no longer be suitable for cultivation in the areas where they were collected (Biodiversity International, 2007). Specific challenges for Africa include the difficulty of storing many tropical seed species (Pardey et al., 1999), and that many crop plants are clonally propagated.

Additional issues include how to ensure sufficient long-term and reliable funding; how to ensure sharing (in particular with IPR issues and the involvement of the private sector); and how to ensure that biodiversity being protected today is relevant to predicted climate changes (for example, drought-resistant varieties are likely to be more important in many parts of SSA in an environment of climate change). Genetic resources have public good characteristics—farmers who cultivate crops and keep livestock with valuable genetic traits do not reap the full benefits of their conservation efforts, suggesting that the private on-farm provision of genetic resources will typically be lower than optimal (Brush, 1992) and hence there is a role for government.

Governments can intervene in genetic conservation in a number of ways that include setting up protected areas where human activity is excluded or limited; subsidies to particular agricultural sectors or direct payments to farmers; empowering villagers to conserve species diversity at the community level, such as in community forests; and developing markets and creating market incentives. These interventions can broadly be divided into market and non-market interventions and each has different implications for funding and sustainability of that funding. Subsidies for particular sectors or direct payments to farmers do not naturally respond to evolutionary changes and are susceptible to rent seeking behavior and so are not considered further in this assessment. Protected area systems that exclude human activities have been established throughout many countries in SSA, although the reality of many is that they are simply "paper parks," where little enforcement occurs due to lack of funding and so degradation and loss of diversity is prevalent. Yet, where protected areas are effective at keeping out people, nearby communities are often harmed as they tend to rely on common areas of land, particularly forests, for nutrition and livelihood activities.

Working with local communities is essential to conserve biodiversity in the longer term (MA, 2005). A number of pre-requisites are required for in situ conservation, particularly with respect to common pool resources (such as village-level forests). Well-defined property rights in favor of local villagers (land tenure security), or at the least legal recognition of the villagers as forest managers, are a pre-requisite for getting villagers to participate in protecting the nearby village forests and hence the genetic diversity contained within the forests (Wiley, 1997; Wiley et al., 2000). Participatory rural appraisals can help decision makers and local communities with communally owned land to determine their own priorities for tree genetic resources and thereby increase the likelihood of successful community in situ conservation responses (FAO, 2007a). Although in some countries and some cultures social norms protect common resources—for example sacred groves are often respected by local communities and not used for extractive purposes—typically enforcement activities are required, whether undertaken by villagers or the government.

At the individual farm level, governments can help to develop institutions and policies that create incentives for local in situ conservation of agricultural diversity. This will be particularly important if farmers increasingly purchase limited varieties rather than using retained seeds. Specific options include the development and promotion of markets including specialty markets that attract premium prices.

The conditions for ex situ collections can be improved through better funding, investigation into new storage technologies, and prioritization. The current understanding of the costs of maintaining ex situ collections and the use of materials from these collections is limited. Key actions that are required therefore include exploring new technologies to improve the possibilities for ex situ conservation policy and methods. Because of the high cost of ex situ conservation, priority setting and sub-regional collaboration to pool resources and expertise and avoid duplication is seen as essential (Biodiversity International, 2007).

The System-wide Genetic Resources Programme (SGRP) of the CGIAR is a new facilitation unit that aims to promote and facilitate research collaboration worldwide so that biodiversity in agriculture can play a much greater part in sustainable development. BioNET is an international not-for-profit initiative that aims to promote taxonomy, particularly in biodiversity rich but economically poor countries, working with local partnerships. Other coordinating mechanisms, like Tree of Life, coordinate research, without the strong emphasis on local capacity development.

Livestock diversity is a particularly important aspect of agricultural biodiversity in SSA. Conserving livestock biodiversity is costly and complicated, and hence priority setting is critical in an environment of limited funding. Ex situ conservation is not practical for conserving animal genetic resources, hence the focus must be on in situ, with a priority being to conserve diversity across species and breeds or strains given that as yet there are no validated breed definitions across species and insufficient application of standardized evaluation protocols for genetic or phenotypic studies in Africa (Wollny, 2003). Measures of breed genetic distances and conservation costs are lacking for many species/breeds (Drucker et al., 2005), and there is little information on the population sizes of existing indigenous animal genetic resources and the changes in the sizes of pure breeding herds/flocks over time in most SSA countries.

Characterizing livestock diversity will offer insights into genetic relationships that help ensure that conservation maintains the greatest amount of diversity. Because livestock diversity is being lost relatively rapidly, both short-term and long-term strategies are required. In the short term, rapid surveys and the estimate of population sizes by species and breed, with the identification of distribution patterns within agroecological zones can provide initial information for policy makers to obtain an overview of the national livestock herd and formulate initial plans to conserve the existing farm animal populations in their habitat (Wollny, 2003). Inadequate valuation of livestock genetic resources may be contributing to genetic erosion, suggesting the need, therefore, for national policies that promote and enable the valuation of genetic resources in order to provide appropriate incentives, and to support efficient allocation of funds for in situ conservation (Wollny, 2003).

In the long run, breed genetic distances and conservation costs and phenotypic data are required, including biological, performance, and economic data and molecular information. Molecular genetic technology and GIS are techniques that can provide information on unique traits and population dynamics.

The development of policy decision-support tools has been proposed as part of wider genetic resource conservation and sustainable use projects in Africa and Asia that are being funded or considered for funding by German Federal Ministry for Economic Cooperation and Development (BMZ) and the Global Environment Facility (GEF). However, such tools have not yet been implemented and so their effectiveness is not known.

Sub-Saharan African livestock breeds will most likely only be conserved as a result of their adaptation and commercialization. This commercialization can be in terms of the end product—meat and livestock products—or in terms of the livestock genes. Once biotechnology has derived identifiable products from indigenous farm animal resources, commercialization of genes will become a possibility and the discussion of intellectual property rights and hence the potential for revenue generation will be made possible (Wollny, 2003). The different possible interventions need to be prioritized, taking into account the cost-effectiveness of each intervention, and market possibilities, thereby enabling a framework to be developed for the marketing of indigenous livestock and products. It is also important for systems to be developed that monitor and control the importation of animal germplasm, given the possible negative impact on diversity of cross-breeding.

Community and village breeding schemes have not been well documented, resulting in insufficient information on how farmers make livestock selections and the cost of community-based solutions to genetic erosion. Site-specific approaches taking into account the specific resources and constraints are most likely the only sustainable solutions (Wollny, 2003). Prioritization can only occur if there is adequate monitoring of changes in genetic diversity. Biodiversity International (formerly IPGRI) is increasingly working with local communities to encourage in situ conservation.

5.6.2 Managing agricultural and wildlife diversity

The conservation of wild biodiversity in SSA is threatened by the negative interaction between wildlife and agriculture. Farmers typically bear the costs of damage from wildlife, such as the destruction of field crops by elephants, without gaining any of the benefits from the wildlife. Farmers attempt to reduce the cost that wildlife imposes on their livelihoods by killing animals that cause damage. There are a number of options that can reduce conflict between agriculture and wildlife and therefore minimize loss of wildlife and wildlife biodiversity. These options include keeping livestock and wildlife apart using physical barriers; paying villagers compensation for damage done to their crops and livestock; and "internalizing the externality" such that farmers bear the costs of wildlife damage but also get control over and therefore benefits from the wildlife and so have an interest in their conservation. Giving the property rights to the local community to manage the resource also provides a mechanism through which outside agencies concerned with biodiversity conservation can negotiate with the community, and through which the community can have the legal backing to protect the resource from "outsiders" and thus derive the benefits (MA, 2005).

The use of physical barriers around protected areas is used in some specific areas but tends to be highly costly, not always effective, and can have negative impacts on the ecological equilibrium of a region, including interfering with natural migration routes. An alternative, less costly barrier approach is for individual households to fence their homesteads, putting their livestock in corrals overnight (Distefano, 2005). Whether households would adopt corralling depends on the costs, perceived benefits and cultural norms.

Financial compensation tends to be highly contentious, rarely effective in practice and depends on external funds. In theory there are compensation schemes in Kenya, but no payouts have been made since 1989 and the official compensation rates are insufficient to cover most costs of damage by wildlife (Distefano, 2005). Paying compensation for wildlife damage does not guarantee that wildlife will be optimally managed, that farmers will refrain from killing wild animals, or that farmers will be honest about the extent of damage by wildlife, and so in tandem with such payments are required conservation incentives and a monitoring and enforcement system (Wells, 1992; MA, 2005).

Schemes that pay compensation or involve communities in wildlife protection are likely to be undermined where property rights are weak. Without strong property rights, farming communities are unable to restrict external access to wildlife; and have little incentive to adopt long-term strategies to manage these resources (MA, 2005). For example, in the francophone territories in West Africa, forest residents have no authority and hence no ability to restrict the exploitation of game by "outside hunters" (Bowen-Jones et al., 2002; MA, 2005) and so any schemes to compensate the local community for wildlife protection would be rendered ineffective.

Devolving responsibility and control over wildlife is being undertaken in a number of countries. In Ghana, encouraging local community management of wildlife resources has involved the proposal that the government Wildlife Division devolve property rights over wildlife to certain local communities, thereby providing an incentive for the community to conserve and manage the natural resource base as the local community now has hunting rights to the wildlife, also an important source of animal protein in their diet (MA, 2005). It is too early to determine whether or not this approach has been a success in terms of reducing farmer-wildlife conflict and improving wildlife numbers and diversity. In Tanzania, community wildlife management strategies feature in the 1998 Wildlife Policy in which locals are granted usufruct rights to the wildlife (Nelson, 2007). In practice, however, there appear to be political and institutional conflicts over the control of the resources, in part a consequence of poorly implemented devolution processes (Nelson, 2007).

The most successful and well-documented cases with respect to improving wildlife conservation and reducing conflict with farmers in SSA come from Southern Africa, particularly the dry savanna zone, where property rights over wildlife are well-defined and enforced and where the tenurial context is much more favorable (MA, 2005). The best known is CAMPFIRE, Communal Areas Management Programme for Indigenous Resources, in Zimbabwe. In South Africa, animal viewing and hunting tourism has resulted in 18% of farmland being converted into game ranches that allow local people to capture non-local values (Heal, 2002; MA, 2005). Wildlife conservation has also increased on the remaining farmland because farmers have property rights to capture wild animals found on their land and sell them to game ranches rather than kill them (Heal, 2002; MA, 2005).

Two key lessons emerge from the literature. Without well-defined and enforced property rights, it is difficult to implement sustainable strategies for the conservation of wildlife where there are natural conflicts between wildlife and livestock and crops. This implies that community-based wildlife management cannot be introduced as a project or as part of a technical assistance package, but needs to be embedded in institutions that build local rights to control and access nearby resources (Nelson, 2007). Further, villagers are unlikely to have the incentive to be involved in community-based schemes unless the wildlife are sufficiently valuable or the villagers are otherwise compensated. In East and Southern Africa there are many charismatic wildlife species that have sufficient value to outsiders, whether for tourism or so-called "trophy hunting."

The challenges are greater in West and Central Africa where these outside sources of revenue are not available. Indeed, wildlife management options that have proven successful in the savannahs of East and Southern Africa may not be applicable in West and Central Africa (Bowen-Jones et al., 2002). Finally, in situations where villagers' incentives cannot be aligned with conserving key species, and for species where even low levels of off-take may cause loss of populations (most likely for large-bodied charismatic species such as gorilla and elephant), such that even "by-catch" is a problem, separation of people and wildlife and strict enforcement may be the only option (Bowen-Jones et al., 2002).

5.7 Forests and Agroforestry

Rural populations rely heavily on forest resources that can complement or substitute for food and income from agriculture. Large and small-scale enterprises extract timber and local communities collect both timber and non-timber forest products (NTFPs), including building materials, fuelwood, charcoal, bushmeat, fruits and vegetables, of which fuelwood is particularly important in SSA. Playing multiple roles, forests also provide ecosystem services and support the conservation of biodiversity.

Agroforestry has the potential to offer wealth-creating opportunities for individual households and communities and also provide alternative products from natural forests, and so its development has the potential to take the pressure off of the natural resource base and reduce environmental degradation while also improving livelihoods. In SSA there is a broad range of tree species that are suitable for domestication and commercialization (Leakey, 2001). Yet forests in SSA are typically poorly protected and therefore over-exploited, and budgets allocated to develop the agroforestry sector in SSA tend to be small, particularly so in countries with significant tracts of natural forest that are being rapidly exploited, such as in D.R. Congo, Gabon, Cameroon and Congo-Brazzaville.

Many of the institutional challenges for natural forests and capture fisheries in SSA are similar and revolve around the challenges of developing institutions to manage common pool resources. Forests are often over-exploited because property rights have not been allocated, or because these property rights are not enforced, resulting in the forests being treated as de facto open access resources. But defining, allocating, and enforcing property rights is costly and so governments need to determine the most cost effective approach. They also need to take into account equity considerations, particularly where local communities have relied on these natural resources.

A typical situation in SSA is that the government owns and controls most of the forested lands and villagers living near these forests do not have legal right to use them or to extract resources from them. The government does not have funds and villagers do not have incentives to protect the forests, and so a classic de facto open access situation arises in which villagers collect from the forests with few institutions in place to ensure sustainable use of them. The forests degrade and villagers must spend more time collecting ever more scarce resources, venturing farther into the forests and causing more environmental damage. Recognizing this reality of poor management and enforcement, a number of countries are introducing participatory forest management (PFM) in which local communities are given some level of control over the forest resources. For example, in Tanzania, depending on the forest classification, villagers might only be responsible for protecting the forest with few direct benefits in return, or might be given full control over a forest, including rights to extract timber and non-timber forest products, and to exclude outsiders from using the resource (Robinson, 2006).

To enable PFM, national laws governing forest ownership and access typically have to be changed. In Tanzania, the 1998 National Forest Policy and the Forest Act of 2002 have enabled PFM to be introduced (MNRT, 1998, 2002ab). The factors that determine whether or not PFM is likely to be successful have not been assessed rigorously. However, PFM is more likely to be successful if the community receives sufficient control over the resources and benefits to make engaging in the process worthwhile. If communities are sufficiently well informed, PFM activities are based on traditional management systems and PFM is seen as a priority by the community, the chances for conservation increase.

5.7.1 Creating market incentives

Certification tends to be seen as appealing because certified timber can attract higher prices and access to premium markets in richer countries. However, certification requires significant organizational and technical expertise from the producers and direct costs in obtaining certification; there is some evidence that although certified producers gain market access, higher prices are typically not realized (MA, 2005; Belcher and Schreckenberg, 2007). Further, certification is largely document-based, and is predicated on formal, structured means of planning and monitoring, and so is biased against traditional societies and the complex land use systems of indigenous and community groups (Bass et al., 2001; Eba'a and Simula, 2002; MA, 2005). Thus far, less than 1% of certified forests are in SSA, with over 90% in Europe and North America (Schulte-Herbruggen and Davies, 2006). Therefore, although there remains scope for certification, the potential in the short to medium term in SSA remains small.

A number of innovative market-based options for improving the contribution of agriculture to the assessment goals are little tested in SSA. These options, some of which are addressed below, could be important over the next decades, particularly for the forestry sector, though their likely contribution is as yet unknown.

Payment for environmental services (PES) schemes are part of a new and more direct conservation paradigm that explicitly recognizes the need to bridge the interests of landowners and outside beneficiaries through compensation payments. PES schemes exist mainly for four services: carbon-sink functions, hydrological protection, biodiversity, and landscape aesthetics/ecotourism. Conditionality—only to pay if the service is actually delivered—is the most innovative feature of PES when compared with traditional conservation tools, but also the one which real world initiatives struggle hardest to meet. New markets for environmental services and approaches in SSA are few and although there appears to be interest and potential for PES there is little evidence to measure its impact.

Although only afforestation and reforestation projects are eligible for credit under the clean development mechanism (CDM) during the first five-year commitment period of the Kyoto protocol, soil carbon sequestration and broader sink activities could become eligible in the future. The CDM involves African countries in selling or trading project-based carbon credits with more industrialized countries thereby combining increased carbon sequestration in agricultural soils with reducing soil degradation, improving soil quality, and preserving biodiversity. However, as yet there is no data concerning the potential for soil carbon sequestration in Africa, suggesting long-term field experiments and pilot projects are needed.

Agroforestry offers multiple benefits for farmers and the broader landscape that are not always clearly articulated in agricultural initiatives. Three key benefits are improvements in soil fertility, provision of animal fodder, and the supply of poles, timber and fuelwood that both benefit households and reduce the pressure on natural forests (Young, 1998; van Noordwijk et al., 2004). Additional benefits include improvements of microclimates, enhancing water conservation, and the production of non-timber forest products including tree fruits. However, although the high demand for home-consumed fuelwood can in part be compensated for through tree planting and agroforestry, in many countries in SSA the demand for charcoal comes from urban areas (Ninnin 1994;

SEI, 2002; MA, 2005). Agroforestry may have particular potential in dryland areas of SSA which have until recently been relatively ignored by research and development agencies (Leakey, 1999; Roy-Macauley and Kalinganire, 2007).

A cluster of challenges have been identified by a number of organizations and working groups including the Southern African Regional Agroforestry 2002 conference. These challenges include the emergence of second generation issues such as pests and diseases, declining investment from national governments, lack of improved planting materials, weak linkages with the private sector and therefore markets for agroforestry products, and uncertainties over climate change, biotechnology, and globalization (Roy-Macauley and Kalinganire, 2007). Further, men and women in SSA typically prioritize different agroforestry products and so are likely to have different preferences for tree varieties and management practices.

In SSA unlike for example, Southeast Asia, markets for non-timber forest products are small (Leakey et al., 2005). There is currently little value added with respect to products from natural forests and from agroforestry, in part because of the lack of focus on postharvest issues including processing and certification, in part because of poorly developed domestic and international markets. There are opportunities to expand market opportunities locally, regionally and internationally that would provide incentives for the development of agroforests. In most of SSA (with the exception of East Africa), many of the potential tree products have potential use in the growing ethnic food industry in Europe and the US (Leakey, 1999). East and southern Africa have the greatest potential to produce indigenous medicinal products for a worldwide market. Increasing market opportunities increases the scope for private sector involvement in research (Leakey et al., 2005).

5.7.2 Forests and energy

Men and women in SSA typically prioritize different agroforestry products and so are likely to have different motivations for adopting particular agroforestry innovations (Gladwin et al., 2002). For example, men are more likely to plant trees in croplands whereas women typically plant trees for fuelwood (Gladwin et al., 2002), reflecting women's role in collecting fuelwood for cooking and heating. Women are likely to benefit significantly from research into rapidly growing tree species that supply fuelwood whereas men might be less likely to support research into fuelwood but more likely to support the development of revenue-generating species. One approach is to identify trees with multiple purposes that can be introduced into an agroforestry system. For example, fruit trees offer market opportunities for farmers, if markets are available for the output, and can improve household nutritional status.

A number of preconditions enable the scaling up of agroforestry research and extension: national and regional peace and security; good and transparent governance; demand for products and market access; sound national and global economies; legislation regarding intellectual property rights; an active process of democratization; functional rural infrastructure; decentralization of decision-making; and resource availability (Cooper and Denning, 1999). International efforts will aid scaling up (Leakey et al., 2005) such as developing skills for domestication of indigenous species, processing and storage, and expanding community training.

SSA countries meet more than 50% of their total primary energy consumption from biomass which predominantly consists of unrefined traditional fuel such as firewood and crop and animal residues. Use of biomass as a source of energy in its traditional forms results in inefficient energy conversion, environmental and health hazards, is time-consuming in terms of collection, and contributes to the degradation of forests. For example, in Tanzania, over 80% of energy consumption is fuelwood.

AKST has played a role in improving traditional bioenergy technologies, such as in the design and supply of efficient cooking stoves. However, so long as fuelwood is free to collect from nearby forests, poor villagers are unlikely to pay for fuel efficient stoves, even when these villagers, predominantly women and children, spend many hours each week or even each day collecting it. Therefore, in the short to medium term, the pressure on forests is more likely to be reduced through the development of village and individual woodlots.

Some SSA countries, e.g., Malawi, South Africa, Ghana, Kenya, Nigeria, Benin and Mauritius, have initiated programs for cogeneration of electricity and heat and the production of biofuels from biomass. The supply of bioelectricity to rural households and rural enterprises is particularly important in rural areas where communities are not connected to the national grid. Saw mills in countries including Tanzania are already using some residues for power and cooking though much is burned thereby causing air pollution. Some residues could be converted to charcoal, and heat gasifiers are relatively simple, though electricity generation is more complex.

Any strategy to promote biofuels needs to be aware of the pressure to expand onto forested and marginal lands, which has the potential to create competition for water, and displacement of people. Large scale monocropping could result in biodiversity loss, soil erosion and nutrient leaching. Many biofuels benefit from economies of scale and so the benefits of biofuel promotion could bypass poor farmers. To include small-scale farmers requires effort to, for example, supply them with seeds and identify biofuel crops that are appropriate for small areas of marginal land.

5.8 Fisheries and Aquaculture

Poor people in SSA are highly dependent on marine and inland capture fisheries and fish from aquaculture for protein and for livelihoods; fish protein constitutes about 22% of overall animal protein intake. Inland fisheries (lakes and rivers) have played a particularly important role in meeting the increased demand for fish in SSA and currently supply the majority of fish consumed in many SSA countries.

Rural fishing communities in SSA generally have a higher percentage of people living below the poverty line than the national average (Whittingham et al., 2003). Catch levels are generally above their maximum sustainable yield levels, which further exacerbates the loss of economic rent from the fishery, increases poverty and loss of livelihoods, and decreases food security (Fisheries Opportunities Assessment, 2006). Increasing demand for fish and the relatively low levels of investment required to earn at least enough to feed a family is likely to attract new entrants into fisheries. Indeed, in 1996, the FAO estimated that artisanal fishing on the continent had doubled in the past decade and that most freshwater fisheries were intensively exploited (FAO, 1996).

Aquaculture has the potential to improve livelihoods and reduce the pressure on capture fisheries yet so far it has been under-exploited. Although the practice has been around since the 1850s and 1920s in South Africa and Kenya respectively, aquaculture is fairly new to many SSA countries. Unlike in other regions, aquaculture currently makes a very small contribution to total fish production; hence capture fisheries will at least in the short to medium term remain critically important in SSA. In many SSA countries, capture fisheries have ill-defined use rights. The resource is usually owned by the state but managed as a "regulated open access", meaning fishers can harvest any quantity of fish if they comply with regulations set by central or local authorities (Akpalu, 2006). This typically results in over-exploitation.

It has been argued that community-based resources are not generally overexploited as predicted by the "tragedy of the commons" (Hardin, 1968). However there may be little incentive for the community to design rules to manage the resource optimally (Ostrom, 2000). Overexploitation is also likely to occur if there is free mobility of fish stocks across communities and countries.

In some countries different ministries have enacted conflicting policies or regulatory policies that do not adequately address the of use illegal fishing technologies. For example, mesh size regulations in multispecies fisheries with small and large pelagic species are heavily violated in many fishing communities (Akpalu, 2006.) Capture fishery regulations are generally poorly enforced as a result of limited state budgets for enforcements, corrupt enforcement officers, and limited punishment for violators.

Commercial fishers who use fishing vessels compete with local fishers for inshore fish stocks, degrade habitat and interrupt the fish food chain, which often leads to conflicts and loss of property (Sterner, 2003). State institutions in Africa are generally weak and unable to cope with the activities of industrialized fleet (Fisheries Opportunities Assessment, 2006). The judicial systems in most countries are reluctant to enforce fishery regulations, which they generally consider less important.

Knowledge of fish stocks and aquatic ecosystems dynamics is important for designing sustainable fishery management policies. Nevertheless, SSA countries lack the relevant data and as a result formulate ad hoc policies to address problems of complex fishery systems. A typical example of such an ad hoc policy is the use of a uniform mesh size regulation to curtail overexploitation of a multispecies fishery that is characterized by seasonal upwellings and transboundary movement.

Although improved fisheries management has been called for, what is considered as appropriate fisheries management is highly debatable. In the past proper fisheries management has implied management for equilibrium production targets such as maximum sustainable yield, with measures to achieve these targets enforced by the state (Tweddle and Magasa, 1989; FAO, 1993). However, centralized fisheries management strategies show little evidence of actually working, particularly in environments characterized by low levels of funding, low staff expertise, and poor technology.

In SSA, new management styles are being developed to achieve a range of management objectives. Many of these advocate an increased participation of communities of resource users. A good example is the GTZ initiative that examines how the management of traditional fisheries can be enhanced to increase their production (Lohmeyer, 2002). Some of the benefits of this management style are that they reduce management costs, improve monitoring of the resources, are democratic, and promise greater regulatory enforcement than do centralized, state-based management strategies. In general, the appropriate models to achieve better management will vary, as do the fisheries to which they are applied, and there is still little consensus on an appropriate model for managing Africa's fisheries.

Policy options that are available to address stock recovery may yield results in the long term, but in the short to medium term, depending on the state of the fishery, will require restricted access. But small-scale fishers who are generally poor have immediate needs, and so even though policies such as seasonal closure in the short-term yield increases in food availability, in the long run, fishers are usually reluctant to participate in implementing or accepting such policies (Akpalu, 2006). The provision of food subsidies to fishing communities in the very short run might be appropriate, followed by creating alternative employment opportunities and encouraging fishers to take up such opportunities in the medium term. After the fish stock recovers, the resource rent could be taxed to recover the food subsidy in the long run.

A key challenge is how to design a local- or community-based policy instrument that can address trans-boundary capture fisheries characterized, in some cases, by unpredictable seasonal stock growths. Due to the potential resource-use externality, any community based fishery management strategy including co-management, without inter-community collaboration, may not be accepted by fishers. Therefore, although it is important that management decisions are decentralized to communities with support from state institutions, communities must be encouraged to synchronize their institutions to minimize free-rider behavior

Aquaculture has the ability to complement wild fish production and thereby take some of the pressure off the wild stocks. SSA's Regional Economic Communities and NEPAD have prioritized aquaculture and are leading regional efforts to direct investments, with clearly defined roles for research and capacity building.

The development of aquaculture is challenged by the costs and technology required for certain aquaculture activities such as hatcheries and grow-out ponds for fish farming. Communities are also challenged by management costs (Ngwale et al., 2004). In some cases, there have been conflicts between aquaculture activities and fishing activities near shore. For example, prawn farming projects in Rufiji and Mafia in Tanzania have met with resistance as it was feared that clearing of mangrove areas to build ponds would cause erosion that could affect seaweed farmers and fishermen (Juma, 2004).

There has been some success in aquaculture technology development based on local species, training of researchers and extension agencies, capacity support for producer organizations in small-scale fisheries and aquaculture, and knowledge support for policy makers and planners. Many challenges remain, including the need for postharvest technologies, value chain and product development, regulations and standards for international trade, provision of information and training to potential farmers, provision of credit to farmers, the availability of fishmeal and fish oil for cultivation of the fish and knowledge of how to mitigate the likely environmental impact of semi-intensive aquaculture.

Integrated farming systems have the advantage of being relatively efficient at converting feeds into fish and typically have lower negative environmental impacts. Aquaculture can have a potentially negative impact, particularly if wild-caught fish are used as feed, if coastal resources such as mangroves are converted to fisheries, or if excessive chemical inputs are used—intensive aquaculture requires the use of compound feeds, pesticides, and antibiotics the spillage of which into natural aquatic systems can negatively affect the ecosystems. Potential negative effects can be reduced through the use of integrated farming systems that avoid using human foodstuffs as an input to aquaculture, strengthening capacity for impact monitoring, and taking lessons from countries such as Thailand that have experienced considerable negative effects from intensive aquaculture. Effort can also be directed towards farming high valued fish such as tilapia, catfish and milkfish which have relatively low fishmeal and fish oil content ratios. However, there is some evidence that substituting vegetable protein for fishmeal may result in higher mortality rates and low rates of growth in several aquatic species and so further research is needed into this area (Delgado et al., 2003). Extensive aquaculture, which relies on natural stocking and feeding of the species, or intensive aquaculture that uses advanced technology to recycle water and other waste can also reduce negative environmental effects.

5.9 Health and Nutrition

Agriculture and health are closely linked in sub-Saharan Africa. Malnutrition is increasingly becoming an urban problem and so the focus must be on both rural and urban areas. More specific options to target micronutrient deficiency includes increasing research into the nutritional value of local and traditional foods, particularly fruits and vegetables, the extent to which they contribute to diets, and the conditions under which farmers would cultivate and market these traditional food sources. Other options, particularly relevant to the urban population, include product development to increase the variety and quality of foods, including fortified foods, as well as targeted information campaigns to increase awareness and encourage the adoption of more nutritious foods. The empowerment and increased involvement of women can help to emphasize the development, adoption, and demand for more nutritious foods, such as orange-flesh sweet potato (Ipomoea batatas), rich in starch, dietary fiber, vitamin A, vitamin C, and vitamin B6. Given the contribution of agriculture to health and nutrition, a strategy of integrated planning and programming among ministries of health, agriculture, livestock, and fisheries would provide opportunities for joint funding of and better synergies among programs.

Nutritional deficiencies are widespread in SSA. Deficiencies of major food molecules, vitamins and minerals lead to such diseases as PEM (protein energy malnutrition); kwashiorkor (deficiency of protein energy intake); pellagra (niacin deficiency); and scurvy (vitamin C deficiency). Yet agricultural policies in SSA continue to emphasize primary agricultural production to the exclusion of micronutrient rich products. Fruits (of which consumption is lower in SSA than all other regions), vegetables, local and traditional foods are generally rich in micronutrients and other dietary requirements. There are a number of approaches to promoting nutritious diet, e.g., research into the nutrient value of local and traditional foods, breeding crops that supplement micronutrients, and ensuring that individuals have access to dietary information on available foods.

Traditional food sources are diverse in SSA. What is lacking is adequate research on the nutritional values of these foods and the extent to which they contribute to diets. Many communities eat plant sources that serve multiple purposes: e.g., as food and as medicine. *Moringa stenopetala*, for example, is a deciduous plant whose cooked leaves are widely used in some western and eastern parts of Africa whereas the roots and leaves of the plant are used for medicine (Mekonnen and Gessesse, 1998). Infectious diseases deplete the human body of minerals and vitamins and the leaves of *Moringa* contain calcium and iron. Information on the nutritional value of traditionally consumed food items will help to promote and popularize their use.

The empowerment of women in agricultural development strategies has been shown to shift the emphasis towards the development and adoption of more nutritious crops such as orange-flesh sweet potato (Hawkes and Ruel, 2006). Establishing the needed infrastructure for research on the health value of foods is one strategy to address the problem of nutrition deficiencies. This requires the concerted effort of governments through NARS, health institutes and other related organizations within the continent.

Biofortification is an innovative approach that links agricultural and nutritional scientists together to breed crops with higher levels of micronutrients. Examples of research being undertaken in SSA include the Africa Biotechnology Sorghum Project, which is attempting to develop a "super sorghum" that is resilient to harsh climates, contains more essential nutrients and is easier to digest when cooked (www.supersorghum.org). However, this approach is controversial. In part this controversy is due to general concerns in SSA over biotechnology, including its impact on health and the environment. Others feel that available funds could be better spent developing existing highly nutritious crops and improving general access to calories.

Individuals can be encouraged to consume a variety of foods with needed nutrients and micronutrients through the development of programs that encourage awareness and develop the habit of choosing foods for nutritional value. Awareness of better nutrition and health can be addressed through developing a farm radio network and disseminating radio scripts in local languages. The scripts are used as teaching and development tools by agriculture extension staff, teachers and community workers. The information in the scripts helps people to understand the conditions that contribute to the alleviation of poverty and hunger through possibly improved nutrition and better health conditions, thus giving the community the tools to take action for change.

In SSA millions of people succumb to diseases such as malaria, tuberculosis and HIV/AIDS that exacerbate and worsen the nutrition status of the population. In many SSA nations, basic nutrition is not fulfilled. Some countries suffer from recurrent drought, forced migration due to conflicts and political instabilities. Malnourished children and the labor available for agriculture are heavily affected due to these unique problems.

In severely AIDS-affected communities of SSA there has been a change in the volume and kinds of crops produced in farming systems. Partly as a result of this, levels of nutrition are falling due to the reliance on starchy staples like cassava and sweet potatoes in Eastern Africa, compared with other more nutritious but labor-intensive traditional crops or protein from animal products. In addition there is lack of understanding of the nutritional value of foods. Lower levels of nutrition result in the increased vulnerability of people to disease and thus to an overall decline in health.

Studies indicate that better nutrition could play a role in prolonging life following HIV infection, and the nutritional status of people living with AIDS plays a large part in determining their current welfare with respect to morbidity (Haddad and Gillespie, 2001). People with endemic diseases such as malaria and tuberculosis also benefit from better nutrition.

At the crop and ecosystem level, nutritional intake is a function of the array of crop and livestock species available in the community basket. For example, researchers are increasingly curious about an apparent geographical convergence of the use of aflatoxin-vulnerable crops, groundnut and maize, and the severity of both malaria and HIV/AIDS in East and Southern Africa. Aflatoxins confer a short-term advantage on people through increased resistance to malaria, but can induce immuno-suppression, which may be linked to a weakening of the immune system even before infection by HIV (CORAF/WECARD, 2003). Therefore, a cautious approach to adopting food items is important (Box 5-5).

In working to assess the nutritional status of a community, it is important to decide on the objectives of the assessment, how the analyses will be done and what actions are feasible. It is important to draw from experience and to design the most appropriate data collection exercise. For example, in an assessment in a large, newly established refugee camp, it might be advisable to collect more than just anthropometric data; in the past, when nutritional status in refugee camps was judged only on anthropometry, deficiency diseases such as scurvy and pellagra were missed.

In many countries, large and expensive surveys, in which a wide variety of nutrition-related data are collected, have been carried out and little action has followed. It has been suggested that ten times the amount spent on a survey should be available for programs aimed at overcoming the deficiencies identified by it. It is important that the information collected be kept to the minimum required to assess or monitor the situation and that surveys be simplified as much as possible. Some information used for the assessment of the nutritional status of a community can also be used for evaluation of programs and for nutritional surveillance.

Box 5-5. Applying an HIV lens.

An HIV lens would, for example, cause an agricultural commercialization policy to take account of the extra risks posed by evening markets and the need for people to travel far to sell their produce. In another example, in Lesotho, instead of pursuing an add-on activity such as distributing condoms along with agricultural extension messages, the Ministry of Agriculture and CARE are now focusing on improving the food and nutrition security of HIV-affected households and those struggling with other shocks and stresses of poverty. Another interesting example is Swaziland's Indlunkhulu initiative. Indlunkhulu refers to the tradition of distributing food from the chief's fields to members of the community who are unable to support themselves. In Swazi law and custom, chiefs are responsible for the welfare of orphans within their area. Agricultural policy has built on this practice to provide a sustainable mechanism for delivering food to orphans and vulnerable children, providing initial agricultural inputs for the Indlunkhulu fields, and developing the agricultural skills of older children who work in them. Agricultural knowledge can also be preserved through the development of HIV-aware and gender-proactive agricultural extension capacity. Farmer life schools, as pioneered in Cambodia and adapted in Kenya and Mozambique, can be developed to bridge gaps in intergenerational knowledge transfer. Capacity constraints may be bypassed through better communications, such as rural radio. There is clearly tremendous scope for agricultural policy to become more HIV-responsive, both to further AIDS-related objectives and to help achieve agricultural objectives. Yet there are no magic bullets. Land-labor ratios and the relative degree of substitutability between household resources, among other factors, will determine the possible responses to HIV/AIDS. If policy becomes more HIV responsive, it will stay relevant and effective. By mainstreaming HIV/AIDS into the policy process and carefully monitoring the results, policymakers will help build up evidence of what works in different contexts, enhance learning, and ultimately leave people better equipped to address the multiple threats of the pandemic.

References

Ahmed, M.M. and J.H. Sanders. 1998. Shifting from extensive to intensive agricultural systems: A case study in the Sudan. Agric. Syst. 58:253-268.

Ahmed, M.M., J.H. Sanders, and W.T. Nell. 2000. New sorghum and millet cultivar introduction in sub-Saharan Africa: Impacts and research agenda. Agric. Syst. 64:55-65.

Akpalu, W. 2006. Individual discount rate and regulatory compliance in a developing country fishery. Available at http://www.csae.ox.ac.uk/conferences/2006-EOI-RPI/papers/csae/Akpalu.pdf. Proc. CSAE Conf. Reducing poverty and inequality, Oxford, 19-21 Mar 2006. Goetborg Univ., Sweden.

Ashby, J. A. 2001. Integrating research on food and the environment: An exit strategy from the rational fool syndrome in agricultural science. Conserv. Ecol. 5:20.

Ashby, J., A.R. Braun, T. Gracia, M.P. Guerrero, L.A. Hernandez, C.A. Quirós, and J.I. Roa. 2000. Investing in farmers as researchers: Experience with local agricultural research committees in Latin America. CIAT, Cali.

Baijukya, F.P. 2004. Adapting to change in banana-based farming systems of Northwest Tanzania: The potential role of herbaceous legumes. PhD Thesis. Available at http://library.wur.nl/wda/dissertations/dis3653.pdf. Wageningen Univ., Netherlands.

Barrett, C.B. 2002. Natural resources management research in the CGIAR: A meta-evaluation: The CGIAR at 31. CGIAR, Washington DC.

Bass, S., K. Thornber, M. Markopoulos, S. Roberts, and M. Grieg-Gran. 2001. Certification's impacts on forests, stakeholders and supply chains. IIED, London.

Batjes, N.H. 2001. Options for increasing carbon sequestration in West African soils: An exploratory study with special focus on Senegal. Land Degrad. Dev. 12:131-142.

Bationo, A., F. Lompo, and S. Koala. 1998. Research on nutrient flows and balances in West Africa: State-of-the-art. Agric. Ecosyst. Environ. 71:19-35.

Behnke, R.H., I. Scoones, and C. Kerven (ed) 1993. Range ecology at disequilibrium: New models of natural variability and pastoral adaptation in African Savannahs. ODI, London.

Beintema, N.M., and G.J. Stads. 2006. Agricultural science and technology indicators (ASTI): Initiative background report. IFPRI, Washington DC.

Bekunda, M., P. Ebanyat, E. Nkonya, D. Mugendi, and J. Msaky. 2004. Soil fertility status, management and research in East Africa. E. Afr. J. Rural Dev. 20:94-112.

Belcher, B., and K. Schreckenberg. 2007. Commercialisation of non-timber forest products: A reality check. Dev. Policy Rev. 25:355-377.

Bentley, J.W. 1994. Facts, fantasies and failures of farmer participatory research. Agric. Human Values 11:140-150.

Bindraban, P.S., and R. Rabbinge. 2003. Technologies that can make a difference: Enhancing agricultural productivity in Africa. Background Pap. 2. Available at http://www.interacademycouncil.net/Object.File/Master/9/055/0.doc. IAC, Amsterdam.

Biodiversity International. 2007. Sub-Saharan Africa. Available at http://www.bioversityinternational.org/regions/sub-saharan_africa/index.asp. Biodiversity Int., Rome.

Bowen-Jones, E., D. Brown, and E. Robinson. 2002. Assessment of the solution-oriented research needed to promote a more sustainable bushmeat trade in Central and West Africa. Available at http://www.defra.gov.uk/wildlife-countryside/resprog/findings/bushmeat.pdf. DEFRA, UK.

Bruinsma, J. (ed) 2003. World agriculture: Towards 2015/2030: An FAO perspective. FAO, Rome.

Brush, S.B. 1992. Farmers' rights and genetic conservation in traditional farming systems. World Dev. 20:1617-1630.

Burley, J. 1987. Small-scale forest enterprises: International forestry research networks: Objectives, problems, and management. Unasylva 39:3-4.

Campbell, B., and J.A. Sayer (ed) 2003. Integrated natural resources management: Linking productivity, the environment and development. Available at http://www.cabi-publishing.org/bookshop/BookDisplay.asp?SubjectArea=Eco&Subject=Forestry&PID=1625. CABI Int., Wallingford.

Chaudenson, R. 2004. De Ouagadougou (1988) à Ouagadougou (2004) en passant par Libreville (2003). (In French). p. 211-221. Penser la Francophonie: Concepts, actions et outils linguistiques. Actes des premières Journées scientifiques communes des réseaux de chercheurs concernant la langue, Ouagadougou, 31 May-1 Jun 2004. AUF, Paris.

Chude, V. 2007. Progress in the implementation of the outcomes of the Africa fertilizer summit. Expert Group Meeting on Agriculture and Rural Transformation in Africa, Addis Ababa, 23-25 Apr 2007. UNECA, Addis Ababa.

CIAT. 2002. The soil, water and nutrient management program: Rising to the challenge of soil degradation. Available at http://www.ciat.cgiar.org/tsbf_institute/pdf/swnm_textonly_brochure.pdf. CIAT, Cali.

Commission for Africa. 2005. Our common interest: Report of the commission for Africa. Available at http://www.commissionforafrica.org/english/report/thereport/english/11-03-05_cr_report.pdf. Commission for Africa, London.

Cooper, P.J.M., and G.L. Denning. 1999. Scaling up the impact of agroforestry research. Development series: Delivering on the promise of agroforestry. ICRAF, Nairobi.

Das, M.D. 1995. Improving the relevance and effectiveness of agricultural extension activities for women farmers: An Andre Mayer research study. FAO, Rome.

Davis, K. 2006. Farmer field schools: A boon or bust for extension in Africa? J. Int. Agric. Ext. Education 13:91-97.

Dejene, A. 2003. Integrated natural resources management to enhance food security: The case for community-based approaches in Ethiopia. Working Pap. 16. ENRS, FAO, Rome.

Dejene, A., E. Shishira, P. Yanda, and F.H. Johnsen 1997. Land degradation in Tanzania: Perception from the village. Tech. Pap. 370. World Bank, Washington DC.

Delgado, C.L., N. Wada, M. Rosegrant, S. Meijer, and M. Ahmed. 2003. Fish to 2020: Supply and demand in changing global markets. IFPRI, Washington DC.

Dercon, S., T. Bold, and C. Calvo. 2004. Insurance for the poor?. Available at http://ideas.repec.org/p/qeh/qehwps/qehwps125.html. Queen Elizabeth House, Univ. Oxford, UK.

Devereux, S. 2003. Policy options for increasing the contribution of social protection to food security. Forum for food security in Southern Africa. IDS, Univ. Sussex, UK.

Distefano, E. 2005. Human wildlife conflict worldwide: Collection of case studies, analysis of management strategies and good practices. Available at http://www.fao.org/SARD/common/ecg/1357/en/HWC_final.pdf. FAO, Rome.

Dongier, P., J.V. Domelen, E. Ostrom, A. Ryan, W. Wakeman, A. Bebbington et al. 2002. Community-driven development. Chapter 9. J. Klugman (ed) A sourcebook for poverty reduction strategies. World Bank, Washington DC.

Donovan, G., and F. Casey.1998. Soil fertility management in sub-Saharan Africa. Tech. Pap. 408. World Bank, Washington DC.

Drucker, A.G., M. Smale, and P. Zambrano. 2005. Valuation and sustainable management of crop and livestock biodiversity: A review of applied economics literature. IFPRI, IPGRI, ILRI, Washington DC.

Eba'a Atyi, R., and M. Simula. 2002. Forest certification: Pending challenges for tropical timber.Tech. Ser. No. 19. Int. Trop. Timber Org. (ITTO), Yokohama, Japan.

Ejigu, B. 1999. Extension policy and its implementation in relation to sustainable land use and food security intervention. p. 249-253. *In* T. Assefa (ed) Food security through sustainable land use policy, institutional land tenure and extension issues in Ethiopia. Proc. 1st. NOVIB Partners Forum on Sust. Land Use, Addis Ababa.

Ellis, J.E. 1992. ILCA's rangeland research programme in the arid and semi-arid zones: Review and recommendations. ILCA, Addis Ababa.
Ellis, J.E., and D.M. Swift. 1988. Stability of African pastoral ecosystems: Alternate paradigms and implications for development. J. Range Manage. 41(6):450-459.
Engels, J.M.M., V.R. Rao, A.H.D. Brown, and M.T. Jackson (ed) 2002. Managing plant genetic diversity. CABI Publ., Wallingford.
Fagerberg-Diallo, S. 2002. Learning to read woke me up!: Motivations, and constraints, in learning to read in Pulaar (Senegal). Available at http://www.iiz-dvv.de/englisch/Publikationen/Ewb_ausgaben/58_2002/eng_ared.htm. DVV Int., Bonn.
Fan, S., P. Hazell, and T. Haque. 2000a. Targeting public investments by agroecological zone to achieve growth and poverty alleviation goals in rural India. Food Policy 25:411-428.
Fan, S., P. Hazell, and S. Thorat. 2000b. Government spending, growth and poverty in rural India. Amer. J. Agric. Econ. 82:1038-1051.
FAO. 1993. Fisheries management in southeast Lake Malawi, the upper Shire River and Lake Malombe. CIFA Fish. Tech. Rep. 21. FAO, Rome.
FAO. 1996. Fisheries and aquaculture in sub-Sahara Africa: Situation and outlook in 1996. FAO, Rome.
FAO. 2002. The state of agricultural biodiversity in the livestock sector: Threats to livestock genetic diversity. FAO, Rome.
FAO, 2007a. SARD and agricultural biodiversity. Policy brief 16. FAO, Rome.
FAO. 2007b. Women and sustainable food security. SD dimensions. Available at http://www.fao.org/sd/fsdirect/fbdirect/fsp001.htm. FAO, Rome.
FARA. 2007. Grounding the African agriculture vision. FARA Ann. Rep. 2006. FARA, Accra.
Farrington, J., and A. Martin. 1988. Farmer participation in agricultural research: A review of concepts and practices. Occas. Pap. 9. ODI, London.
Fisheries Opportunities Assessment. 2006. Coastal Resources Center, Univ. Rhode Island and Florida Int. Univ.
Fok, M., W. Liang, D. Romano, and P. Yotopoulos. 2007. Genetically modified seeds and decommodification: An analysis based on the Chinese cotton case. Working Pap. 312. Stanford Center Int. Dev., CA.
Gandah, M., A. Stein, A.J. Brouwer, and J. Bouma, 2000. Dynamics of spatial variability of millet growth and yields at three sites in Niger, West Africa, and implications for precision agriculture research. Agric. Syst. 63:123-140.
Gebremedhin, B., and S. Swinton. 2003. Investment in soil conservation in northern Ethiopia: The role of tenure security and public programs. Agric. Econ. 29:69-84.
Gillespie, S. 2006. Understanding the links between agriculture and health: Agriculture and HIV/AIDS. Focus 13, Brief 7. IFPRI, Washington DC.
Gladwin, C.H., J.S. Peterson, and R. Uttaro. 2002. Agroforestry innovations in Africa: Can they improve soil fertility on women farmers' fields? Available at http://www.africa.ufl.edu/asq/v6/v6i1a10.htm. African Studies Q., Univ. Florida.
Haddad, L., and S. Gillespie. 2001. Effective food and nutrition policy responses to HIV/AIDS: What we know and what we need to know. J. Int. Dev. 13:487-511.
Hall, A.J., L. Mytelka, and B. Oyeyinka. 2004. Innovation systems: Concepts and implications for agricultural research policy and practice. UN Univ. Maastricht, Netherlands.
Hall, A.J., L. Mytelka, and B. Oyeyinka. 2006. Concepts and guidelines for diagnostic assessments of agricultural innovation capacity. The UNU-MERIT Working Pap. Ser. 17. UN Univ. Maastricht, Netherlands.
Hall, A., and S. Nahdy. 1999. New methods and old institutions: The "systems context" of farmer participatory research in national agricultural research systems: The case of Uganda. AgRen Pap. 93. ODI, DFID, London.
Hall, M. 2001. Farming systems and poverty: Improving farmer's livelihood in a changing world. FAO, Rome.
Hardin, G. 1968. The tragedy of the commons. Science 162:1243-1248.
Hartwich, F., M.V. Gottret, S. Babu, and J. Tola, 2007. Building public-private partnerships for agricultural innovation in Latin America: Lessons from capacity strengthening. Disc. Pap. 699. IFPRI, Washington DC.
Hawkes, C., and M.T. Ruel (ed) 2006. Understanding the links between agriculture and health. 2020 Vision Focus 13. IFPRI, Washington DC.
Heal, G. 2002. Nature and the marketplace. Island Press, Washington, DC.
Heemskerk, W., N. Lema, D. Guindo, C. Schouten, Z. Semgalawe, H. Verkuijl et al. 2003. A guide to demand-driven agricultural research: The client-oriented research management approach. Royal Trop. Inst. (KIT), Amsterdam.
Heidhues, F., A. Atsain, H. Nyangito, M. Padilla, G. Ghersi, and J.-C. Le Vallée. 2004. 2020: development strategies and food and nutrition security in Africa: An assessment. Disc. Pap. 38. Available at http://www.ifpri.org/2020/dp/dp38/2020dp38.pdf. IFPRI, Washington DC.
Hiernaux, P. 1993. The crisis of Sahelian pastoralism: Ecological or economic? ILCA, Addis Ababa.
Hilhorst, T., and F. Muchena. 2000. Nutrients on the move: Soil fertility dynamics in African farming systems. IIED, London.
Homann, S., and B. Rischkowsky. 2001. Integration of indigenous knowledge into land use planning for the communal range lands of Namibia. Indigenous Knowl. Dev. Monitor 9:3.
IAC. 2004. Realizing the promise and potential of African agriculture science and technology to improve food security and agricultural productivity in Africa. Report of ad-hoc follow up Committee. InterAcademy Council, Amsterdam.
Ibrahim, M.N.M., J. Tharmaraj, and J.B. Schiere. 1988. Effect of variety and nitrogen application on nutritive value of rice straw and stubble. Biol. Waste 24:267-274.
IFPRI. 2005. Can public & private sectors work together for the poor?. Available at http://www.ifpri.org/pubs/newsletters/ifpriforum/if200506.htm. IFPRI, Washington DC.
Inocencio, A., H. Sally, and D.J. Merry. 2003. Innovative approaches to agricultural water use for improving food security in sub-Saharan Africa. Working Pap. 55. IWMI, Colombo.
Jarvis, D., B. Sthapit, and L. Sears (ed) 2000. Conserving agricultural biodiversity in situ: A scientific basis for sustainable agriculture. IPGRI, Rome.
Johnson, N., N. Lilja, and J.A. Ashby. 2003. Measuring the impact of user participation in natural resource management research. *In* D.J. Watson (ed) Proc. Int. Conf. Impact of agricultura research and development: Why has impact assessment research not made more of a difference? CIMMYT, Mexico.
Juma, S.K. 2004. Tanzania marine and coastal environment management project (MACEMP): Environmental and social situation analysis. Min. Natural Resources Tourism, United Rep. Tanzania.
Kamara, A., and H. Sally. 2004. Water management options for food security in South Africa: Scenarios, simulations, and policy implications. Dev. South. Afr. 21:365-384.
Kante, S. 2001. Gestion de la Fertilite Des Sols par Classe d'Exploitation au Mali-Sud. (In French). Doctoral thesis. Wageningen Univ., Netherlands.
Leakey, R.R.B. 1999. Agroforestry for biodiversity in farming systems. p. 127-146. *In* W.W. Collins and C.O Qualet (ed) Biodiversity in agroecosystems. CRC Press, Boca Raton FL.
Leakey, R.R.B. 2001. Win:Win landuse strategies for Africa 1: Building on experience with agroforests in Asia and Latin America. Int. For. Rev. 3:321-330.
Leakey, R.R.B., Z. Tchoundjeu, K. Schreckenberg, S.E. Shackleton, and C.M. Shackleton. 2005. Agroforestry tree products (AFTPs): Targeting poverty reduction and enhanced livelihoods. Int. J. Agric. Sustain. 3:1-23.
Lilja, N. 2003. Impact of participatory plant breeding: An overview. Available at http://

www.sgrp.cgiar.org/Publications/QofS-FinalReportFeb18.pdf. p. 30. L. Sperling (ed) Proc. Workshop: The quality of science in participatory plant breeding. Rome, 30 Sept-4 Oct 2002. CGIAR, Washington DC.

Lohmeyer, U. (ed) 2002. Back to basics: Traditional inland fisheries management and enhancement systems in sub-Saharan Africa and their potential for development. COFAD, Tutzing and GTZ, Eschborn.

Lundgren, L. 1993. Twenty years of soil conservation in Eastern Africa. Reg. Soil Conserv. Unit Tech. Handbook 4. SIDA, Nairobi.

MA. 2005. Ecosystems and human well-being: Policy responses. Millennium Ecosystem Assessment, Island Press, Washington DC.

Mafongoya, P.L., E. Kuntashula, and G. Sileshi. 2006. Managing soil fertility and nutrient cycles through fertilizer trees in southern Africa. p. 273-289. N. Uphoff et al. (ed) Biological approaches to sustainable soil systems. Taylor and Francis, UK.

Maganga, F.P., H.L. Kiwasila, I.H. Juma, and J.A. Butterworth. 2004. Implications of customary norms and laws for implementing IWRM: Findings from Pangani and Rufiji basins, Tanzania. Phys. Chem. Earth 29:1335-1342.

Mando, A, 1997. The role of termites and mulch in the rehabilitation of crusted Sahelian soils. Ph.D thesis. Wageningen Univ., Netherlands.

Masters, W. 2002. Overview and priorities for science and technology in West Africa. USAID West Africa regional program to end hunger in Africa (IEHA). USAID, Washington DC.

Mavedzenge, B., F. Murimbarimba, and C. Mudzivo. 1999. Experiences of farmer participation in soil fertility research in southern Zimbabwe. Managing Africa's soils 5. Nottingham Press, UK.

Meilleur, B.A., and T. Hodgkin. 2004. In situ conservation of crop wild relatives: Status and trends. Biodiversity Conserv. 13:663-684.

Mekonnen, Y., and A. Gessesse. 1998. Documentation on the uses of and its possible antileishamnial and antifertility effects. SINET: Ethiop. J. Sci. 21:287-295.

Melmed-Sanjak, J. and S. Lastarria-Cornhiel. 1998. Development of good practice guidelines for land leasing: Some preliminary considerations. Internal Rep. to FAO. Land Tenure Center, Univ. Wisconsin, Madison.

MNRT (Ministry of Natural Resources and Tourism). 1998. National Forest Policy. Gov. Tanzania, Dar es Salaam.

MNRT (Ministry of Natural Resources and Tourism). 2002a. Beekeeping Act No. 15. Gov. Tanzania, Dar es Salaam.

MNRT (Ministry of Natural Resources and Tourism). 2002b. Forest Act No. 14. Gov. Tanzania, Dar es Salaam.

Molden, D.J., and C. de Fraiture. 2004. Investing in water for food, ecosystems and livelihood. IWMI, Colombo.

Murwira, H.K., and H. Kirchmann. 1993. Comparison of carbon and nitrogen mineralisation of cattle manure subjected to different treatments, in Zimbabwean and Swedish soils. R. Merrkx and J. Mulongoy (ed) The dynamics of soil organic matter in relation to the sustainability of tropical agriculture. John Wiley, Leuven.

Murwira, H.K., P. Mutuo, N. Nhamo, A.E. Marandu, R. Rabeson, M. Mwale et al. 2002. Fertilizer equivalency values of organic materials of differing quality. p. 113-122. B. Vanlauwe et al. (ed) Integrated nutrient management in sub-Saharan Africa. CAB Int., Wallingford.

Nagayets, O. 2005. Small farms: Current status and key trends: Information brief. Future of Small Farms Res. Workshop, Wye College, 26-29 Jun 2005. Wye, UK.

Nelson, F. 2007. Emergent or illusory? Community wildlife management in Tanzania. Issue Pap. 146. Int. Inst. Environ. Dev., London.

NEPAD. 2004. Implementing the comprehensive Africa agriculture development programme and restoring food security in Africa. Available at www.nepad.org/2005/files/documents/172.pdf. NEPAD, South Africa.

Ngugi, D. 2005. ISNAR division's stakeholders need assessment for Eastern and Central Africa: Synthesis report. IFPRI, Addis Ababa.

Ngwale J., G. Kamukala, G.W. Bashagi, and R. Lima. 2004. Kilwa district consultations: Design of Rufiji-Mafia-Kilwa seascape marine coastal resources management programme. Prepared for the World Wildlife Fund, Dar es Salaam.

Ninnin, B. 1994. Elements d'Economie spatiale des energies traditionelles: Application au cas de cinq pays sahelens: Burkina Faso, Gambie, Mali, Niger, Senegal. (In French). Review of policies in the traditional energy sector. World Bank, Washington DC.

Njobe, B. 2003. NEPAD's comprehensive African agricultural program. p. 7-8. *In* A. Omore and D. Sheikh (ed) Study on science and technology strategies for improving agricultural productivity and food security in eastern and central African countries. Proc. Conf. Workshop E. and C. Africa, Nairobi, 31 Jan-2 Feb 2003. ASARECA, IAC, Entebbe.

Oba, G., and D.G. Kotile. 2001. Assessment of landscape level degradation in southern Ethiopia: Pastoralists versus ecologists. Land Degrad. Dev. 12:461-475.

Ochieng, C.M.O. 2007. Revitalising African agriculture through innovative business models and organizational arrangements: Promising developments in the traditional crops sector. J. Modern Afr. Studies 45:143-169.

Omamo, S.W. 2003. Policy research on African agriculture: Trends, gaps and challenges. Res. Rep. 2. ISNAR, The Hague.

Onduru, D.D., F.M. Muchena, L. Gachimbi, and F. Maina. 2002. Experiences with farmer field schools in Kenya: Literature review on IPM, IPPM, and INM. INMASP, The Hague.

Ostrom, E. 2000. Collective action and the evolution of social norms. J. Econ. Perspect. 14:137-158.

Pardey, P.G., B. Koo, B.D. Wright, M.E. Van Dusen, B. Skovmand, and S.Taba. 1999. Costing the ex situconservation of genetic resources: Maize and wheat at CIMMYT. EPTD Disc. Pap. 52. IFPRI, CIMMYT, Mexico City.

Pretty, J., and R. Hine. 2001. Reducing food poverty with sustainable agriculture: A summary of new evidence. Final report from the SAFE-World research project. Univ. Essex, UK.

Probst, K., J. Hagmann, M. Fernandez, and J.A. Ashby. 2003. Understanding participatory research in the context of natural resource management: Paradigms, approaches and typologies. ODI, London.

Reardon, T., E. Crawford, V. Kelly, and B. Diagana. 1995. Promoting farm investment for sustainable intensification of African agriculture. Available at http://aec.msu.edu/fs2/polsyn/no3.htm. Michigan State Univ., East Lansing.

Robinson, E. 2006. Assessment of stakeholder knowledge, awareness, and perceptions on participatory forest management. Available at http://easternarc.or.tz/downloads/Thematic-strategies/PFM%20Awareness%20Baseline%20Survey%20Nov%202006.pdf. United Rep. Tanzania, Dar es Salaam.

Rothschild, G. 2005. The requirements for Science and Technology in agriculture in sub-Saharan Africa. Pres. APGOOD Meeting, House of Commons, London, 8 Nov 2005. Available at http://www.odi.org.uk/speeches/apgood_oct05/apgood_nov8/NotesRothschild.pdf. All Party Parliamentary Group Overseas Dev., London.

Roy-Macauley, A., and A. Kalinganire. 2007. Agroforestry innovations for greening dryland Africa: Interest and obstacles. ICRAF, Nairobi.

Sanchez, P.A. 2000. Linking climate change research with food security and poverty reduction in the tropics. Agric. Ecosyst. Environ. 82:371-383.

Sanchez, P.A. 2002. Soil fertility and hunger in Africa. Science 295:2019-2020.

Sandford, S. 1983. Management of pastoral development in the third world. John Wiley, ODI, London.

Sawadogo, J.P., and V. Stamm. 2000. Local perceptions of indigenous land tenure systems: The cause of peasants, women, and dignitaries in a rural province of Burkina Faso. J. Mod. Afr. Studies 38:279-294.

Scherr, S.J. 1999. Soil degradation: A threat to developing country food security by 2020? FAE Disc. Pap. 27. IFPRI, Washington DC.
Schiere, J.B., M.N.M. Ibrahim, and H. van Keulen. 2002. The role of livestock for sustainability: Criteria and scenario studies under varying resource allocation. Agric. Ecosyst. Environ. 90:139-153.
Schulte-Herbruggen, B., and G. Davies. 2006. Wildlife conservation and tropical timber certification. Conserv. Rep. 6. Zoological Soc. London.
Scoones, I. (ed) 1995. Living with uncertainty: New directions in pastoral development in Africa. Intermediate Tech. Publ., London.
Scoones, I. 2005. Making technology work for the poor: Governing science and technology. Pres. APGOOD Meeting, House of Commons, London. 8 Nov 2005. Available at http://www.odi.org.uk/events/apgood/Agric_in_Africa_05/apgood_nov8/NotesScoones.pdf. All Party Parliamentary Group Overseas Dev., London.
Seck, M. 1992. Unearthing the impacts of land tenure. Available at http://archive.idrc.ca/books/reports/v222/unearth.html. Reports 22:2. IDRC, Ottawa.
SEI (Stockholm Environment Institute). 2002. Charcoal potential in southern Africa (CHAPOSA). Available at http://www.sei.se/chaposa/chaposaresources.html#final_report. SEI, Stockholm.
Sissoko, K. 1998. Et demain l'Agriculture? Options techniques et mesures politiques pour un développement agricole durable en Afrique subsaharienne: Cas du cercle de Koutiala en zone sud du Mali. (In French). PhD Thesis, Wageningen Univ., Netherlands.
Slingerland, M.A. 2000.Mixed farming: Scope and constraints in West Africa savanna. PhD thesis, Wageningen Univ., Netherlands.
Smalberger, S.A., U. Singh, S.H. Chien, J. Henao, and P.W. Wilkens. 2006. Development and validation of a phosphate rock decision support system. Agron. J. 98:471-483.
Smaling, E.M.A., S.M. Nandwa, and B.H. Janssen. 1997. Soil fertility in Africa is at stake. *In* R.J. Buresh et al. (ed) Replenishing soil fertility in Africa. Spec. Pub. 51. Soil Sci. Soc. Am. Madison WI.
Snapp, S.S., M.J. Blackie, and C. Donovan. 2003. Realigning research and extension to focus on farmers' constraints and opportunities. Food Policy 28:349-363.
Sterner, T. 2003. Policy instrument for environmental and natural resource management. Resource for the Future, Washington DC.
Stoorvogel, J.J., and E.M.A. Smaling. 1990. Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000. Rep. 28. Winand Staring Centre, Wageningen.
Swift, M.J., L. Bohren, S.E. Carter, A.-M. Izac, and P.L. Woomer. 1994. Biological management of tropical soils: Integrating process research with farm practice. p. 209-228. P.L. Woomer and M.J. Swift (ed) The biological management of tropical soil fertility.John Wiley, Chichester.
Toulmin, C., and J.F. Quan. 2000. Evolving land rights, policy, and tenure in Africa. DFID, IIED, NRI, London.
Toure, R. 2003. Research for development in West and Central Africa. IDRC, Ottawa.
Toure, M., and M. Noor. 2001. The role of agricultural technology in food and nutritional security in Africa: Special program for African agricultural research (SPAAR). Afr. J. Food Nutr. Security 1:35-44.
Tripp, R. 2003. Strengthening the enabling environment for agricultural technology development in sub-Saharan Africa. Working Pap. 212. ODI, London.
Tweddle, D., and J. Magasa. 1989. Assessment of multispecies cichlid fisheries of the southeast arm of Lake Malawi, Africa. J. Cons. Int. Explor. Mer. 45:209-222.
UNECA. 2007. Overview of the sustainable development report on Africa: Agricultural and rural transformation in Africa. Meeting of Afr. Comm. Sust. Dev. 5th, Addis Ababa, 22-25 Oct 2007. UN Econ. Comm. Africa, Addis Ababa.
UNEP. 1999. Global environment outlook 2000. UNEP, Nairobi.
UNESCAP. 2007. What is good governance? Available at http://www.unescap.org/pdd/prs/ProjectActivities/Ongoing/gg/governance.asp. UNESCAP, Bangkok.
Van Noordwijk, M., J. Poulsen, and P. Ericksen. 2004. Filters, flows and fallacies: Quantifying off-site effects of land use change. Agric. Ecosyst. Environ. 104:19-34.
Weber, G. 1996. Legume-based technologies for African savannas: Challenges for research and development. Biol. Agric. Hort. 13:309-333.
Weight, D., and V. Kelly. 1998. Restoring soil fertility in sub-Saharan Africa. Int. Dev. Policy Synthesis 37. Michigan State Univ., East Lansing.
Weismann, U., N.F. Gichuki, P.B. Kiteme, and H. Liniger. Mitigating conflicts over scarce water resources in the highland-lowland system of Mount Kenya. Mountain Res. Dev. 20:10-15.
Wells, M. 1992. Biodiversity conservation, affluence and poverty: Mismatched costs and benefits and efforts to remedy them. Ambio 21:237-243.
Wezel, A., and T. Rath. 2002. Resource conservation strategies in agroecosystems of semi-arid West Africa. J. Arid Environ. 51:383-400.
Whittingham, E., J. Campbell, and P. Townsley. 2003. Poverty and reefs.Vol. 1, 2. UNESCO, Paris.
Wiley, L. 1997. Villagers as forest managers and governments "learning to let go": The case of Duru-Haitemba and Mgori forests in Tanzania. Forest Participation Ser. 9. IIED, London.
Wiley, L., A. Akida, O. Haule, H. Haulle, S. Hozza, C. Kavishe et al. 2000. Community management of forests in Tanzania: A status report at the beginning of the 21st Century. Forest Trees People 42:36-45.
Wollny, C. 2003. The need to conserve animal genetic resources in Africa: Should policy makers be concerned? Ecol. Econ. 45:341-351.
World Bank. 2002. Stakeholder interaction on key issues session II: Combating soil fertility degradation in sub-Saharan Africa: Stakeholder meeting agenda item 5. Available at http://www.worldbank.org/html/cgiar/publications/agm2002/5session2soil.pdf. Ann. Gen. Meeting, Washington DC, 30-31 Oct 2002. World Bank, Washington DC.
Yaron, G., and J. White. 2002. Mainstreaming cross-cutting themes in programme and sector aid: The case of environmental issues. Nat. Res. Perspect. 77. Available at http://www.odi.org.uk/publications/nrp/77.pdf. ODI, DFID, London.
Young, A. 1998. Agroforestry for soil conservation. 2nd ed. CAB Int., Wallingford

Annex A
SSA Authors and Review Editors

Benin
Peter Neuenschwander • International Institute of Tropical Agriculture
Simplice Davo Vodouhe • Pesticide Action Network

Democratic Republic of Congo
Dieudonne Athanase Musibono • University of Kinshasa

Ethiopia
Assefa Admassie • Ethiopian Economic Policy Research Institute
Gezahegn Ayele • EDRI-IFPRI
Joan Kagwanja • Economic Commission for Africa
Yalemtsehay Mekonnen • Addis Ababa University

Ghana
John-Eudes Andivi Bakang • Kwame Nkrumah University of Science and Technology (KNUST)
Daniel N. Dalohoun • United Nations University MERIT/INRA
Felix Yao Mensa Fiadjoe • University of Ghana
Carol Mercey Markwei • University of Ghana Legon
Joseph (Joe) Taabazuing • Ghana Institute of Management and Public Administration (GIMPA)

Kenya
Tsedeke Abate • ICRISAT-Nairobi
Susan Kaaria • Ford Foundation
Washington O. Ochola • Egerton University
Wellington Otieno • Maseno University
Wahida Patwa Shah • World Agroforestry Centre (ICRAF)
Anna Stabrawa • United Nations Environment Programme

Madascagar
Roland Xavier Rakotonjanahary • FOFIFA (National Center for Applied Research for Rural Development)

Mozambique
Manuel Amane • Instituto de Investigação Agrícola de Moçambique (IIAM)
Patrick Matakala • World Agroforestry Centre, ICRAF Southern Africa Regional Programme

Netherlands
Nienke Beintema • IFPRI

Nigeria
Sanni Adunni • Ahmadu Bello University
Michael Chidozie Dike • Ahmadu Bello University
V.I.O. Ndirika • Ahmadu Bello University
Stella Williams • Obafemi Awolowo University

Rwanda
Agnes Abera Kalibata • Ministry of Agriculture

Senegal
Julienne Kuiseu • CORAF/WECARD
Moctar Toure • Independent

South Africa
Marnus Gouse • University of Pretoria

Sri Lanka
Francis Ndegwa Gichuki • International Water Management Institute (IWMI)

Tanzania
Roshan Abdallah • Tropical Pesticides Research Institute (TPRI)
Stella N. Bitende • Ministry of Livestock and Fisheries Development
Sachin Das • Animal Diseases Research Institute
Evelyne Lazaro • Sokoine University of Agriculture
Razack Lokina • University of Dar es Salaam
Lutgard Kokulinda Kagaruki • Animal Diseases Research Institute
Elizabeth J.Z. Robinson • University of Dar es Salaam

Uganda
Apili E.C. Ejupu • Ministry of Agriculture, Animal Industries and Fisheries
Apophia Atukunda • Environment Consultancy League
Dan Nkoowa Kisauzi • Nkoola Institutional Development Associates (NIDA)
Imelda Kashaija • National Agriculture Resource Organization (NARO)

United Kingdom
Nicola Spence • Central Science Laboratory

United States
Wisdom Akpalu • Environmental Economics Research & Consultancy (EERAC)
Patrick Avato • The World Bank
Mohamed Bakarr • Center for Applied Biodiversity Science, Conservation International
Amadou Makhtar Diop • Rodale Institute

Annex A

SSA Authors and Review Editors

Benin
Peter Neuenschwander • International Institute of Tropical Agriculture
Simplice Davo Vodouhe • Pesticide Action Network

Democratic Republic of Congo
Dieudonne Athanase Musibono • University of Kinshasa

Ethiopia
Assefa Admassie • Ethiopian Economic Policy Research Institute
Gezahegn Ayele • EDRI-IFPRI
Joan Kagwanja • Economic Commission for Africa
Yalemtsehay Mekonnen • Addis Ababa University

Ghana
John-Eudes Andivi Bakang • Kwame Nkrumah University of Science and Technology (KNUST)
Daniel N. Dalohoun • United Nations University MERIT/INRA
Felix Yao Mensa Fiadjoe • University of Ghana
Carol Mercey Markwei • University of Ghana Legon
Joseph (Joe) Taabazuing • Ghana Institute of Management and Public Administration (GIMPA)

Kenya
Tsedeke Abate • ICRISAT-Nairobi
Susan Kaaria • Ford Foundation
Washington O. Ochola • Egerton University
Wellington Otieno • Maseno University
Wahida Patwa Shah • World Agroforestry Centre (ICRAF)
Anna Stabrawa • United Nations Environment Programme

Madascagar
Roland Xavier Rakotonjanahary • FOFIFA (National Center for Applied Research for Rural Development)

Mozambique
Manuel Amane • Instituto de Investigação Agrícola de Moçambique (IIAM)
Patrick Matakala • World Agroforestry Centre, ICRAF Southern Africa Regional Programme

Netherlands
Nienke Beintema • IFPRI

Nigeria
Sanni Adunni • Ahmadu Bello University
Michael Chidozie Dike • Ahmadu Bello University
V.I.O. Ndirika • Ahmadu Bello University
Stella Williams • Obafemi Awolowo University

Rwanda
Agnes Abera Kalibata • Ministry of Agriculture

Senegal
Julienne Kuiseu • CORAF/WECARD
Moctar Toure • Independent

South Africa
Marnus Gouse • University of Pretoria

Sri Lanka
Francis Ndegwa Gichuki • International Water Management Institute (IWMI)

Tanzania
Roshan Abdallah • Tropical Pesticides Research Institute (TPRI)
Stella N. Bitende • Ministry of Livestock and Fisheries Development
Sachin Das • Animal Diseases Research Institute
Evelyne Lazaro • Sokoine University of Agriculture
Razack Lokina • University of Dar es Salaam
Lutgard Kokulinda Kagaruki • Animal Diseases Research Institute
Elizabeth J.Z. Robinson • University of Dar es Salaam

Uganda
Apili E.C. Ejupu • Ministry of Agriculture, Animal Industries and Fisheries
Apophia Atukunda • Environment Consultancy League
Dan Nkoowa Kisauzi • Nkoola Institutional Development Associates (NIDA)
Imelda Kashaija • National Agriculture Resource Organization (NARO)

United Kingdom
Nicola Spence • Central Science Laboratory

United States
Wisdom Akpalu • Environmental Economics Research & Consultancy (EERAC)
Patrick Avato • The World Bank
Mohamed Bakarr • Center for Applied Biodiversity Science, Conservation International
Amadou Makhtar Diop • Rodale Institute

David Knopp • Emerging Markets Group (EMG)
Pedro Marques • The World Bank
Harry Palmier • The World Bank
Stacey Young • US Agency for International Development Zambia
Charlotte Wonani • University of Zambia

Zimbabwe

Chiedza L. Muchopa • University of Zimbabwe
Lindela R. Ndlovu • National University of Science and Technology
Idah Sithole-Niang • University of Zimbabwe

Annex B
Peer Reviewers

Belgium
Kevin Akoyi • Vredeseilanden

Benin
Peter Neuenschwander • International Institute of Tropical Agriculture
René Tokannou • IFOAM

Canada
R. Thomas Beach • Agricultural Institute of Canada
Jean Marcel Laferrière • CIDA
Ian Myles • CIDA

Egypt
Malcolm Beveridge • WorldFish Center

France
Anna Lipchitz • Agence Française de Développement
Didier Picard • INRA
Bernard Faye • CIRAD
Jean-François Renard • CIRAD
Bruno Vindel • Ministère de l'Agriculture et de la Pêche

Germany
Jan van Aken • Greenpeace International

Ireland
Garvin McCann • Irish Aid

Kenya
DEWA Africa section • United Nations Environment Programme
Christian Borgemeister • ICIPE
Peter Ewell • US Agency for International Development
Ade Freeman • International Livestock Research Institute
Michael Hall • US Agency for International Development
Evans Mwangi • University of Nairobi
Deborah Scott • ACORD
Nalini Sharma • United Nations Environment Programme
Anna Stabrawa • United Nations Environment Programme
Robert Wagner • World Agroforesty Center

Malawi
Elton Laisi • Center for Development Research and Information in Southern Africa

Mozambique
Alsácia Atanásio • Ministry of Science and Technology

Poland
Ursula Soltysiak • AgroBio Test

Senegal
Mamadou Khouma • Independent

South Africa
Raymond Auerback • Rainman Landcare Foundation

Sweden
Pernilla Malmer • Swedish University for Agricultural Sciences

United Kingdom
Defra • Government of United Kingdom
Zoe Cokeliss • UNEP World Conservation Monitoring Centre
Stuart Coupe • Practical Action
Emma Hennessey • Defra
Lera Miles • UNEP World Conservation Monitoring Centre
Rebecca Murphy • Biocontrol News and Information, CABI

United States
Jonathan Agwe • World Bank
Mohamed Bakarr • Conservation International
Philip Bereano • University of Washington
Doug Gurian-Sherman • Union of Concerned Scientists
Michael Hansen • Consumers Union
Reimund Kube • World Wildlife Fund
Bruno Losch • World Bank
Karen Luz • World Wildlife Fund
Stephen D. Mink • World Bank
Michael Morris • World Bank
Donald Osborn • Bisharat, Ltd.
Susan J. Owens • U.S. Department of Agriculture
Ivette Perfecto • University of Michigan
Cameron Pittelkow • Pesticide Action Network, North America
Margaret Reeves • Pesticide Action Network, North America
Julienne Roux • World Bank
Sara Scherr • Ecoagriculture Partners
Doreen Stabinsky • College of the Atlantic
Giuseppe Topa • World Bank

Zambia
Simon Heck • WorldFish Center

Zimbabwe
Prosper Matondi • Center for Rural Development
Cathy Rutivi • Consumers International

Annex C

Glossary

Agriculture A linked, dynamic social-ecological system based on the extraction of biological products and services from an ecosystem, innovated and managed by people. It thus includes cropping, animal husbandry, fishing, forestry, biofuel and bioproducts industries, and the production of pharmaceuticals or tissue for transplant in crops and livestock through genetic engineering. It encompasses all stages of production, processing, distribution, marketing, retail, consumption and waste disposal.

Agricultural biodiversity Encompasses the variety and variability of animals, plants and microorganisms necessary to sustain key functions of the agroecosystem, its structure and processes for, and in support of, food production and food security.

Agricultural extension Agricultural extension deals with the creation, transmission and application of knowledge and skills designed to bring desirable behavioral changes among people so that they improve their agricultural vocations and enterprises and, therefore, realize higher incomes and better standards of living.

Agricultural innovation Agricultural innovation is a socially constructed process. Innovation is the result of the interaction of a multitude of actors, agents and stakeholders within particular institutional contexts. If agricultural research and extension are important to agricultural innovation, so are markets, systems of government, relations along entire value chains, social norms, and, in general, a host of factors that create the incentives for a farmer to decide to change the way in which he or she works, and that reward or frustrate his or her decision.

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

Agricultural subsidies Agricultural subsidies can take many forms, but a common feature is an economic transfer, often in direct cash form, from government to farmers. These transfers may aim to reduce the costs of production in the form of an input subsidy, e.g., for inorganic fertilizers or pesticides, or to make up the difference between the actual market price for farm output and a higher guaranteed price. Subsidies shield sectors or products from international competition.

Agricultural waste Farming wastes, including runoff and leaching of pesticides and fertilizers, erosion and dust from plowing, improper disposal of animal manure and carcasses, crop residues and debris.

Agroecological Zone A geographically delimited area with similar climatic and ecological characteristics suitable for specific agricultural uses.

Agroecology The science of applying ecological concepts and principles to the design and management of sustainable agroecosystems. It includes the study of the ecological processes in farming systems and processes such as: nutrient cycling, carbon cycling/sequestration, water cycling, food chains within and between trophic groups (microbes to top predators), lifecycles, herbivore/predator/prey/host interactions, pollination etc. Agroecological functions are generally maximized when there is high species diversity/perennial forest-like habitats.

Agroecosystem A biological and biophysical natural resource system managed by humans for the primary purpose of producing food as well as other socially valuable nonfood goods and environmental services. Agroecosystem function can be enhanced by increasing the planned biodiversity (mixed species and mosaics), which creates niches for unplanned biodiversity.

Agroforestry A dynamic, ecologically based, natural resources management system that through the integration of trees in farms and in the landscape diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels. Agroforestry focuses on the wide range of work with trees grown on farms and in rural landscapes. Among these are fertilizer trees for land regeneration, soil health and food security; fruit trees for nutrition; fodder trees that improve smallholder livestock production; timber and fuelwood trees for shelter and energy; medicinal trees to combat disease; and trees that produce gums, resins or latex products. Many of these trees are multipurpose, providing a range of social, economic and environmental benefits.

AKST Agricultural Knowledge, Science and Technology (AKST) is a term encompassing the ways and means used to practice the different types of agricultural activities, and including both formal and informal knowledge and technology.

Alien Species A species occurring in an area outside of its historically known natural range as a result of intentional or accidental dispersal by human activities. Also referred to as introduced species or exotic species.

Aquaculture The farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated. Aquaculture practiced in a marine environment is called mariculture.

Average Rate of Return Average rate of return takes the whole expenditure as given and calculates the rate of return to the global set of expenditures. It indicates whether or not the entire investment package was successful, but it does not indicate whether the allocation of resources between investment components was optimal.

Biodiversity The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; including diversity within species and gene diversity among species, between species and of ecosystems.

Bioelectricity Electricity derived from the combustion of biomass, either directly or co-fired with fossil fuels such as coal and natural gas. Higher levels of conversion efficiency can be attained when biomass is gasified before combustion.

Bioenergy (biomass energy) Bioenergy is comprised of bioelectricity, bioheat and biofuels. Such energy carriers can be produced from energy crops (e.g., sugar cane, maize, oil palm), natural vegetation (e.g., woods, grasses) and organic wastes and residues (e.g., from forestry and agriculture). Bioenergy refers also to the direct combustion of biomass, mostly for heating and cooking purposes.

Biofuel Liquid fuels derived from biomass and predominantly used in transportation. The dominant biofuels are ethanol and biodiesel. Ethanol is produced by fermenting starch contained in plants such as sugar cane, sugar beet, maize, cassava, sweet sorghum or beetroot. Biodiesel is typically produced through a chemical process called trans-esterification, whereby oily biomass such as rapeseed, soybeans, palm oil, jatropha seeds, waste cooking oils or vegetable oils is combined with methanol to form methyl esters (sometimes called "fatty acid methyl ester" or FAME).

Bioheat Heat produced from the combustion of biomass, mostly as industrial process heat and heating for buildings.

Biological Control The use of living organisms as control agents for pests, (arthropods, nematodes mammals, weeds and pathogens) in agriculture. There are three types of biological control:

Conservation biocontrol: The protection and encouragement of local natural enemy populations by crop and habitat management measures that enhance their survival, efficiency and growth.

Augmentative biocontrol: The release of natural enemies into crops to suppress specific populations of pests over one or a few generations, often involving the mass production and regular release of natural enemies.

Classical biocontrol: The local introduction of new species of natural enemies with the intention that they establish and build populations that suppress particular pests, often introduced alien pests to which they are specific.

Biological Resources Include genetic resources, organisms or parts thereof, populations, or any other biotic component of ecosystems with actual or potential use or value for humanity.

Biotechnology The IAASTD definition of biotechnology is based on that in the Convention on Biological Diversity and the Cartagena Protocol on Biosafety. It is a broad term embracing the manipulation of living organisms and spans the large range of activities from conventional techniques for fermentation and plant and animal breeding to recent innovations in tissue culture, irradiation, genomics and marker-assisted breeding (MAB) or marker assisted selection (MAS) to augment natural breeding. Some of the latest biotechnologies, called "modern biotechnology", include the use of *in vitro* modified DNA or RNA and the fusion of cells from different taxonomic families, techniques that overcome natural physiological reproductive or recombination barriers.

Biosafety Referring to the avoidance of risk to human health and safety, and to the conservation of the environment, as a result of the use for research and commerce of infectious or genetically modified organisms.

Blue Water The water in rivers, lakes, reservoirs, ponds and aquifers. Dryland production only uses green water, while irrigated production uses blue water in addition to green water.

BLCAs Brookered Long-term Contractual Arrangements (BLCAs) are institutional arrangements often involving a farmer cooperative, or a private commercial, parastatal or a state trading enterprise and a package (inputs, services, credit, knowledge) that allows small-scale farmers to engage in the production of a marketable commodity, such as cocoa or other product that farmers cannot easily sell elsewhere.

Catchment An area that collects and drains rainwater.

Capacity Development Any action or process which assists individuals, groups, organizations and communities in strengthening or developing their resources.

Capture Fisheries The sum (or range) of all activities to harvest a given fish resource from the "wild". It may refer to the location (e.g., Morocco, Gearges Bank), the target resource (e.g., hake), the technology used (e.g., trawl or beach seine), the social characteristics (e.g., artisanal, industrial), the purpose (e.g., commercial, subsistence, or recreational) as well as the season (e.g., winter).

Carbon Sequestration The process that removes carbon dioxide from the atmosphere.

Cellulosic Ethanol Next generation biofuel that allows converting not only glucose but also cellulose and hemi-cellulose—the main building blocks of most biomass—into ethanol, usually using acid-based catalysis or enzyme-based reactions to break down plant fibers into sugar, which is then fermented into ethanol.

Climate Change Refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use.

Clone A group of genetically identical cells or individuals that are all derived from one selected individual by vegetative propagation or by asexual reproduction, breeding of completely inbred organisms, or forming genetically identical organisms by nuclear transplantation.

Commercialization The process of increasing the share of income that is earned in cash (e.g., wage income, surplus production for marketing) and reducing the share that is earned in kind (e.g., growing food for consumption by the same household).

Cultivar A cultivated variety, a population of plants within a species of plant. Each cultivar or variety is genetically different.

Deforestation The action or process of changing forest land to non-forested land uses.

Degradation The result of processes that alter the ecological characteristics of terrestrial or aquatic (agro)ecosystems so that the net services that they provide are reduced. Continued degradation leads to zero or negative economic agricultural productivity.

For loss of *land* in quantitative or qualitative ways, the term *degradation* is used. For water resources rendered unavailable for agricultural and non-agricultural uses, we employ the terms *depletion* and *pollution*. *Soil* degradation refers to the processes that reduce the capacity of the soil to support agriculture.

Desertification Land degradation in drylands resulting from various factors, including climatic variations and human activities.

Domesticated or Cultivated Species Species in which the evolutionary process has been influenced by humans to meet their needs.

Domestication The process to accustom animals to live with people as well as to selectively cultivate plants or raise animals in order to increase their suitability and compatibility to human requirements.

Driver Any natural or human-induced factor that directly or indirectly causes a change in a system.

Driver, direct A driver that unequivocally influences ecosystem processes and can therefore be identified and measured to different degrees of accuracy.

Driver, endogenous A driver whose magnitude can be influenced by the decision maker. The endogenous or exogenous characteristic of a driver depends on the organizational scale. Some drivers (e.g., prices) are exogenous to a decision-maker at one level (a farmer) but endogenous at other levels (the nation-state).

Driver, exogenous A driver that cannot be altered by the decision-maker.

Driver, indirect A driver that operates by altering the level or rate of change of one or more direct drivers.

Ecoagriculture A management approach that provides fair balance between production of food, feed, fuel, fiber, and biodiversity conservation or protection of the ecosystem.

Ecological Pest Management (EPM) A strategy to manage pests that focuses on strengthening the health and resilience of the entire agro-ecosystem. EPM relies on scientific advances in the ecological and entomological fields of population dynamics, community and landscape ecology, multi-trophic interactions, and plant and habitat diversity.

Economic Rate of Return The net benefits to all members of society as a percentage of cost, taking into account externalities and other market imperfections.

Ecosystem A dynamic complex of plant, animal, and microorganism communities and their nonliving environment interacting as a functional unit.

Ecosystem Approach A strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way. An ecosystem approach is based on the application of appropriate scientific methodologies focused on levels of biological organization, which encompass the essential structure, processes, functions, and interactions among organisms and their environment. It recognizes that humans, with their cultural diversity, are an integral component and managers of many ecosystems.

Ecosystem Function An intrinsic ecosystem characteristic related to the set of conditions and processes whereby an ecosystem maintains its integrity (such as primary productivity, food chain biogeochemical cycles). Ecosystem functions include such processes as decomposition, production, pollination, predation, parasitism, nutrient cycling, and fluxes of nutrients and energy.

Ecosystem Management An approach to maintaining or restoring the composition, structure, function, and delivery of services of natural and modified ecosystems for the goal of achieving sustainability. It is based on an adaptive, collaboratively developed vision of desired future conditions that integrates ecological, socioeconomic, and institutional perspectives, applied within a geographic framework, and defined primarily by natural ecological boundaries.

Ecosystem Properties The size, biodiversity, stability, degree of organization, internal exchanges of material and energy among different pools, and other properties that characterize an ecosystem.

Ecosystem Services The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services such as nutrient cycling that maintain the conditions for life on Earth. The concept "ecosystem goods and services" is synonymous with ecosystem services.

Ecosystem Stability A description of the dynamic properties of an ecosystem. An ecosystem is considered stable if it returns to its original state shortly after a perturbation (resilience), exhibits low temporal variability (constancy), or does not change dramatically in the face of a perturbation (resistance).

Eutrophication Excessive enrichment of waters with nutrients, and the associated adverse biological effects.

Ex-ante The analysis of the effects of a policy or a project based only on information available before the policy or project is undertaken.

Ex-post The analysis of the effects of a policy or project based on information available after the policy or project has been implemented and its performance is observed.

Ex-situ Conservation The conservation of components of biological diversity outside their natural habitats.

Externalities Effects of a person's or firm's activities on others which are not compensated. Externalities can either hurt or benefit others—they can be negative or positive. One negative externality arises when a company pollutes the local environment to produce its goods and does not compensate the negatively affected local residents. Positive externalities can be produced through primary education, which benefits not only primary school students but also society at large. Governments can reduce negative externalities by regulating and taxing goods with negative externalities. Governments can increase positive externalities by subsidizing goods with positive externalities or by directly providing those goods.

Fallow Cropland left idle from harvest to planting or during the growing season.

Farmer-led Participatory Plant Breeding Researchers and/or development workers interact with farmer-controlled, managed and executed PPB activities, and build on farmers' own varietal development and seed systems.

Feminization The increase in the share of women in an activity, sector or process.

Fishery Generally, a fishery is an activity leading to harvesting of fish. It may involve capture of wild fish or the raising of fish through aquaculture.

Food Security Food security exists when all people of a given spatial unit, 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, and that is obtained in a socially acceptable and ecologically sustainable manner.

Food Sovereignty The right of peoples and sovereign states to democratically determine their own agricultural and food policies.

Food System A food system encompasses the whole range of food production and consumption activities. The food system includes farm input supply, farm production, food processing, wholesale and retail distribution, marketing, and consumption.

Forestry The human utilization of a piece of forest for a certain purpose, such as timber or recreation.

Forest Systems Forest systems are lands dominated by trees; they are often used for timber, fuelwood, and non-wood forest products.

Gender Refers to the socially constructed roles and behaviors of, and relations between, men and women, as opposed to sex, which refers to biological differences. Societies assign specific entitlements, responsibilities and values to men and women of different social strata and sub-groups.

Worldwide, systems of relation between men and women tend to disadvantage women, within the family as well as in public life. Like the hierarchical framework of a society, gender roles and relations vary according to context and are constantly subject to changes.

Genetic Engineering Modifying genotype, and hence phenotype, by transgenesis.

Genetic Material Any material of plant, animal, microbial or other origin containing functional units of heredity.

Genomics The research strategy that uses molecular characterization and cloning of whole genomes to understand the structure, function and evolution of genes and to answer fundamental biological questions.

Globalization Increasing interlinking of political, economic, institutional, social, cultural, technical, and ecological issues at the global level.

GMO (Genetically Modified Organism) An organism in which the genetic material has been altered anthropogenically by means of gene or cell technologies.

Governance The framework of social and economic systems and legal and political structures through which humanity manages itself. In general, governance comprises the traditions, institutions and processes that determine how power is exercised, how citizens are given a voice, and how decisions are made on issues of public concern.

Global Environmental Governance The global biosphere behaves as a single system, where the environmental impacts of each nation ultimately affect the whole. That makes a coordinated response from the community of nations a necessity for reversing today's environmental decline.

Global Warming Refers to an increase in the globally averaged surface temperature in response to the increase of well-mixed greenhouse gases, particularly CO_2.

Global Warming Potential An index, describing the radiative characteristics of well-mixed greenhouse gases, that represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in absorbing outgoing infrared radiation. This index approximates the time-integrated warming effect of a unit mass of a given greenhouse gas in today's atmosphere, relative to that of carbon dioxide.

Green Revolution An aggressive effort since 1950 in which agricultural researchers applied scientific principles of genetics and breeding to improve crops grown primarily in less-developed countries. The effort typically was accompanied by collateral investments to develop or strengthen the delivery of extension services, production inputs and markets and develop physical infrastructures such as roads and irrigation.

Green Water Green water refers to the water that comes from precipitation and is stored in unsaturated soil. Green water is typically taken up by plants as evapotranspiration.

Ground Water Water stored underground in rock crevices and in the pores of geologic materials that make up the Earth's crust. The upper surface of the saturate zone is called the *water table*.

Growth Rate The change (increase, decrease, or no change) in an indicator over a period of time, expressed as a percentage of the indicator at the start of the period. Growth rates contain several sets of information. The first is whether there is any change at all; the second is what direction the change is going in (increasing or decreasing); and the third is how rapidly that change is occurring.

Habitat Area occupied by and supporting living organisms. It is also used to mean the environmental attributes required by a particular species or its ecological niche.

Hazard A potentially damaging physical event, phenomenon and/or human activity, which my cause injury, property damage, social and economic disruption or environmental degradation.

Hazards can include latent conditions that may represent future threats and can have different origins.

Household All the persons, kin and non-kin, who live in the same or in a series of related dwellings and who share income, expenses and daily subsistence tasks. A basic unit for socio-cultural and economic analysis, a household may consist of persons (sometimes one but generally two or more) living together and jointly making provision for food or other essential elements of the livelihood.

Industrial Agriculture Form of agriculture that is capital-intensive, substituting machinery and purchased inputs for human and animal labor.

Infrastructure The facilities, structures, and associated equipment and services that facilitate the flows of goods and services between individuals, firms, and governments. It includes public utilities (electric power, telecommunications, water supply, sanitation and sewerage, and waste disposal); public works (irrigation systems, schools, housing, and hospitals); transport services (roads, railways, ports, waterways, and airports); and R&D facilities.

Innovation The use of a new idea, social process or institutional arrangement, material, or technology to change an activity, development, good, or service or the way goods and services are produced, distributed, or disposed of.

Innovation system Institutions, enterprises, and individuals that together demand and supply information and technology, and the rules and mechanisms by which these different agents interact.

In recent development discourse agricultural innovation is conceptualized as part and parcel of social and ecological organization, drawing on disciplinary evidence and understanding of how knowledge is generated and innovations occur.

In-situ Conservation The conservation of ecosystems and natural habitats and the maintenance and recovery of viable populations of species in their natural habitats and surroundings and, in the case of domesticated or cultivated species, in the surroundings where they have developed their distinctive properties and were managed by local groups of farmers, fishers or foresters.

Institutions The rules, norms and procedures that guide how people within societies live, work, and interact with each other. Formal institutions are written or codified rules, norms and procedures. Examples of formal institutions are the Constitution, the judiciary laws, the organized market, and property rights. Informal institutions are rules governed by social and behavioral norms of the society, family, or community. Cf. *Organization*.

Integrated Approaches Approaches that search for the best use of the functional relations among living organisms in relation to the environment without excluding the 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.

Integrated Assessment A method of analysis that combines results and models from the physical, biological, economic, and social sciences, and the interactions between these components in a consistent framework to evaluate the status and the consequences of environmental change and the policy responses to it.

Integrated Natural Resources Management (INRM) An approach that integrates research of different types of natural resources into stakeholder-driven processes of adaptive management and innovation to improve livelihoods, agroecosystem resilience, agricultural productivity and environmental services at community, eco-regional and global scales of intervention and impact. INRM thus aims to help to solve complex real-world problems affecting natural resources in agroecosystems.

Integrated Pest Management (IPM) The procedure of integrating and applying practical management methods to manage insect populations so as to keep pest species from reaching damaging levels while avoiding or minimizing the potentially harmful effects of pest management measures on humans, non-target species, and the environment. IPM tends to incorporate assessment methods to guide management decisions.

Intellectual Property Rights (IPRs) Legal rights granted by governmental authorities to control and reward certain products of human intellectual effort and ingenuity.

Internal Rate of Return The discount rate that sets the net present value of the stream of the net benefits equal to zero. The internal rate of return may have multiple values when the stream of net benefits alternates from negative to positive more than once.

International Dollars Agricultural R&D investments in local currency units have been converted into international dollars by deflating the local currency amounts with each country's inflation ration (GDP deflator) of base year 2000. Next, they were converted to US dollars with a 2000 purchasing power parity (PPP) index. PPPs are synthetic exchange rates used to reflect the purchasing power of currencies.

Knowledge The way people understand the world, the way in which they interpret and apply meaning to their experiences. Knowledge is not about the discovery of some finale objective "truth" but about the grasping of subjective culturally conditioned products emerging from complex and ongoing processes involving selection, rejection, creation, development and transformation of information. These processes, and hence knowledge, are inextricably linked to the social, environmental and institutional context within which they are found.

Scientific knowledge: Knowledge that has been legitimized and validated by a formalized process of data gathering, analysis and documentation.

Explicit knowledge: Information about knowledge that has been or can be articulated, codified, and stored and exchanged. The most common forms of explicit knowledge are manuals, documents, procedures, cultural artifacts and stories. The information about explicit knowledge also can be audio-visual. Works of art and product design can be seen as other forms of explicit knowledge where human skills, motives and knowledge are externalized.

Empirical knowledge: Knowledge derived from and constituted in interaction with a person's environment. Modern communication and information technologies, and scientific instrumentation, can extend the "empirical environment" in which empirical knowledge is generated.

Local knowledge: The knowledge that is constituted in a given culture or society.

Traditional (ecological) knowledge: The cumulative body of knowledge, practices, and beliefs evolved by adaptive processes and handed down through generations. It may not be indigenous or local, but it is distinguished by the way in which it is acquired and used, through the social process of learning and sharing knowledge.

Knowledge Management A systematic discipline of policies, processes, and activities for the management of all processes of knowledge generation, codification, application and sharing of information about knowledge.

Knowledge Society A society in which the production and dissemination of scientific information and knowledge function well, and in which the transmission and use of valuable experiential knowledge is optimized; a society in which the information of those with experiential knowledge is used together with that of scientific and technical experts to inform decision-making.

Land Cover The physical coverage of land, usually expressed in terms of vegetation cover or lack of it. Influenced by but not synonymous with land use.

Land Degradation The reduction in the capability of the land to produce benefits from a particular land use under a specific form of land management.

Landscape An area of land that contains a mosaic of ecosystems, including human-dominated ecosystems. The term cultural landscape is often used when referring to landscapes containing significant human populations.

Land Tenure The relationship, whether legally or customarily defined, among people, as individuals or groups, with respect to land and associated natural resources (water, trees, minerals, wildlife, and so on).

Rules of tenure define how property rights in land are to be allocated within societies. Land tenure systems determine who can use what resources for how long, and under what conditions.

Land Use The human utilization of a piece of land for a certain purpose (such as irrigated agriculture or recreation). Land use is influenced by, but not synonymous with, land cover.

Leguminous Cultivated or spontaneous plants which fix atmospheric nitrogen.

Malnutrition Failure to achieve nutrient requirements, which can impair physical and/or mental health. It may result from consuming too little food or a shortage or imbalance of key nutrients (e.g., micronutrient deficiencies or excess consumption of refined sugar and fat).

Marginal Rates of Return Calculates the returns to the last dollar invested on a certain activity. It is usually estimated through econometric estimation.

Marker Assisted Selection (MAS) The use of DNA markers to improve response to selection in a population. The markers will be closely linked to one or more target loci, which may often be quantitative trait loci.

Minimum Tillage The least amount possible of cultivation or soil disturbance done to prepare a suitable seedbed. The main purposes of minimum tillage are to reduce tillage energy consumption, to conserve moisture, and to retain plant cover to minimize erosion.

Model A simplified representation of reality used to simulate a process, understand a situation, predict an outcome or analyze a problem. A model can be viewed as a selective approximation, which by elimination of incidental detail, allows hypothesized or quantified aspects of the real world to appear manipulated or tested.

Multifunctionality In IAASTD, multifunctionality is used solely to express the inescapable interconnectedness of agriculture's different roles and functions. The concept of multifunctionality recognizes agriculture as a multi-output activity producing not only commodities (food, feed, fibers, agrofuels, medicinal products and ornamentals), but also non-commodity outputs such as environmental services, landscape amenities and cultural heritages (See Global SDM Text Box)

Natural Resources Management Includes all functions and services of nature that are directly or indirectly significant to humankind, i.e., economic functions, as well as other cultural and ecological functions or social services that are not taken into account in economic models or not entirely known.

Nanotechnology The engineering of functional systems at the atomic or molecular scale.

Net Present Value (NPV) Net present value is used to analyze the profitability of an investment or project, representing the difference between the discounted present value of benefits and the discounted present value of costs. If NPV of a prospective project is positive, then the project should be accepted. The analysis of NPV is sensitive to the reliability of future cash inflows that an investment or project will yield.

No-Till Planting without tillage. In most systems, planter-mounted coulters till a narrow seedbed assisting in the placement of fertilizer and seed. The tillage effect on weed control is replaced by herbicide use.

Obesity A chronic physical condition characterized by too much body fat, which results in higher risk for health problems such as high blood pressure, high blood cholesterol, diabetes, heart disease and stroke. Commonly it is defined as a Body Mass Index (BMI) equal to or more than 30, while overweight is equal to or more than 25. The BMI is an idex of weight-for-height and is defined as the weight in kilograms divided by the square of the height in meters (kg/m^2).

Organic Agriculture An ecological production management system that promotes and enhances biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony.

Organization Organizations can be formal or informal. Examples of organizations are government agencies (e.g., police force, ministries, etc.), administrative bodies (e.g., local government), non-governmental organizations, associations (e.g., farmers' associations) and private companies (firms). Cf. *Institutions*.

Orphan Crops Crops such as tef, finger millet, yam, roots and tubers that tend to be regionally or locally important for income and nutrition, but which are not traded globally and receive minimal attention by research networks.

Participatory Development A process that involves people (population groups, organizations, associations, political parties) actively and significantly in all decisions affecting their lives.

Participatory Domestication The process of domestication that involves agriculturalists and other community members actively and significantly in making decisions, taking action and sharing benefits.

Participatory Plant Breeding (PPB) Involvement of a range of actors, including scientists, farmers, consumers, extension agents, vendors, processors and other industry stakeholders—as well as farmer and community-based organizations and non-government organization (NGOs) in plant breeding research and development.

Participatory Varietal Selection (PVS) A process by which farmers and other stakeholders along the food chain are involved with researchers in the selection of varieties from formal and farmer-based collections and trials, to determine which are best suited to their own agroecosystems' needs, uses and preferences, and which should go ahead for finishing, wider release and dissemination. The information gathered may in turn be fed back into formal-led breeding programs.

Pesticide A toxic chemical or biological product that kills organisms (e.g., insecticides, fungicides, weedicides, rodenticides).

Poverty There are many definitions of poverty.

Absolute Poverty: According to a UN declaration that resulted from the World Summit on Social Development in 1995, absolute poverty is a condition characterized by severe deprivation of basic human needs, including food, safe drinking water, sanitation facilities, health, shelter, education and information. It depends not only on income but also on access to services.

Dimensions of Poverty: The individual and social characteristics of poverty such as lack of access to health and education, powerlessness or lack of dignity. Such aspects of deprivation experienced by the individual or group are not captured by measures of income or expenditure.

Extreme Poverty: Persons who fall below the defined poverty line of US$1 income per day. The measure is converted into local currencies using purchasing power parity (PPP) exchange rates. Other definitions of this concept have identified minimum subsistence requirements, the denial of basic human rights or the experience of exclusion.

Poverty Line: A minimum requirement of welfare, usually defined in relation to income or expenditure, used to identify the poor. Individuals or households with incomes or expenditure below the poverty line are poor. Those with incomes or expenditure equal to or above the line are not poor. It is common practice to draw more than one poverty line to distinguish different categories of poor, for example, the extreme poor.

Private Rate of Return The gain in net revenue to the private firm/business divided by the cost of an investment expressed in percentage.

Processes A series of actions, motions, occurrences, a method, mode, or operation, whereby a result or effect is produced.

Production Technology All methods that farmers, market agents and consumers use to cultivate, harvest, store, process, handle, transport and prepare food crops, cash crops, livestock, etc. for consumption.

Protected Area A geographically defined area which is designated or regulated and managed to achieve specific conservation objectives as defined by society.

Public Goods A good or service in which the benefit received by any one party does not diminish the availability of the benefits to others, and/or where access to the good cannot be restricted. Public goods have the properties of non-rivalry in consumption and non-excludability.

Public R&D Investment Includes R&D investments done by government agencies, nonprofit institutions, and higher-education agencies. It excludes the private for-profit enterprises.

Research and Development (R&D) Organizational strategies and methods used by research and extension program to conduct their work including scientific procedures, organizational modes, institutional strategies, interdisciplinary team research, etc.

Scenario A plausible and often simplified description of how the future may develop based on explicit and coherent and internally consistent set of assumptions about key driving forces (e.g., rate of technology change, prices) and relationships. Scenarios are neither predictions nor projections and sometimes may be based on a "narrative storyline". Scenarios may be derived from projections but are often based on additional information from other sources.

Science, Technology and Innovation Includes all forms of useful knowledge (codified and tacit) derived from diverse branches of learning and practice, ranging from basic scientific research to engineering to local knowledge. It also includes the policies used to promote scientific advance, technology development, and the commercialization of products, as well as the associated institutional innovations. *Science* refers to both basic and applied sciences. *Technology* refers to the application of science, engineering, and other fields, such as medicine. *Innovation* includes all of the processes, including business activities that bring a technology to market.

Shifting Cultivation Found mainly in the tropics, especially in humid and subhumid regions. There are different kinds; for example, in some cases a settlement is permanent, but certain fields are fallowed and cropped alternately ("rotational agriculture"). In other cases, new land is cleared when the old is no longer productive.

Slash and Burn Agriculture A pattern of agriculture in which existing vegetation is cleared and burned to provide space and nutrients for cropping.

Social Rate of Return The gain to society of a project or investment in net revenue divided by cost of the investment, expressed by percentage.

Soil and Water Conservation (SWC) A combination of appropriate technology and successful approach. Technologies promote the sustainable use of agricultural soils by minimizing soil erosion, maintaining and/or enhancing soil properties, managing water, and controlling temperature. Approaches explain the ways and means which are used to realize SWC in a given ecological and socioeconomic environment.

Soil Erosion The detachment and movement of soil from the land surface by wind and water in conditions influenced by human activities.

Soil Function Any service, role, or task that a soil performs, especially: (a) sustaining biological activity, diversity, and productivity; (b) regulating and partitioning water and solute flow; (c) filtering, buffering, degrading, and detoxifying potential pollutants; (d) storing and cycling nutrients; (e) providing support for buildings and other structures and to protect archaeological treasures.

Staple Food (Crops) Food that is eaten as daily diet.

Soil Quality The capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. In short, the capacity of the soil to function.

Subsidy Transfer of resources to an entity, which either reduces the operating costs or increases the revenues of such entity for the purpose of achieving some objective.

Subsistence Agriculture Agriculture carried out for the use of the individual person or their family with few or no outputs available for sale.

Sustainable Development Development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Sustainable Land Management (SLM) A system of technologies and/or planning that aims to integrate ecological with socio-economic and political principles in the management of land for agricultural and other purposes to achieve intra- and intergenerational equity.

Sustainable Use of Natural Resources Natural resource use is sustainable if specific types of use in a particular ecosystem are considered reasonable in the light of both the internal and the external perspective on natural resources. "Reasonable" in this context means that all actors agree that resource use fulfils productive, physical, and cultural functions in ways that will meet the long-term needs of the affected population.

Technology Transfer The broad set of deliberate and spontaneous processes that give rise to the exchange and dissemination of information and technologies among different stakeholders. As a generic concept, the term is used to encompass both diffusion of technologies and technological cooperation across and within countries.

Terms of Trade The *international terms* of trade measures a relationship between the prices of exports and the prices of imports, this being known strictly as the barter terms of trade. In this sense, deterioration in the terms of trade could have resulted if unit prices of exports had risen less than unit prices for imports. The *inter-sectoral terms of trade* refers to the terms of trade between sectors of the economy, e.g., rural and urban, agriculture and industry.

Total Factor Productivity A measure of the increase in total output which is not accounted for by increases in total inputs. The total factor productivity index is computed as the ratio of an index of aggregate output to an index of aggregate inputs.

Tradeoff Management choices that intentionally or otherwise change the type, magnitude, and relative mix of services provided by ecosystems.

Transgene An isolated gene sequence used to transform an organism. Often, but not always, the transgene has been derived from a different species than that of the recipient.

Transgenic An organism that has incorporated a functional foreign gene through recombinant DNA technology. The novel gene exists in all of its cells and is passed through to progeny.

Undernourishment Food intake that is continuously inadequate to meet dietary energy requirement.

Undernutrition The result of food intake that is insufficient to meet dietary energy requirements continuously, poor absorption, and/or poor biological use of nutrients consumed.

Urban and Peri-Urban Agriculture Agriculture occurring within and surrounding the boundaries of cities throughout the world and includes crop and livestock production, fisheries and forestry, as well as the ecological services they provide. Often multiple farming and gardening systems exist in and near a single city.

Value Chain A set of value-adding activities through which a product passes from the initial production or design stage to final delivery to the consumer.

Virtual Water The volume of water used to produce a commodity. The adjective "virtual" refers to the fact that most of the water used to produce a product is not contained in the product. In accounting virtual water flows we keep track of which parts of these flows refer to green, blue and grey water, respectively.

The real-water content of products is generally negligible if compared to the virtual-water content.

Waste Water "Grey" water that has been used in homes, agriculture, industries and businesses that is not for reuse unless it is treated.

Watershed The area which supplies water by surface and subsurface flow from precipitation to a given point in the drainage system.

Watershed Management Use, regulation and treatment of water and land resources of a watershed to accomplish stated objectives.

Water Productivity An efficiency term quantified as a ration of product output (goods and services) over water input.

Expressions of water productivity. Three major expressions of water productivity can be identified: 1) the amount of carbon gain per unit of water transpired by the leaf or by the canopy (photosynthetic water productivity); 2) the amount of water transpired by the crop (biomass water productivity); or 3) the yield obtained per unit amount of water transpired by the crop (yield water productivity).

Agricultural water productivity relates net benefits gained through the use of water in crop, forestry, fishery, livestock and mixed agricultural systems. In its broadest sense, it reflects the objectives of producing more food, income, livelihood and ecological benefits at less social and environmental cost per unit of water in agriculture.

Physical water productivity relates agricultural production to water use—more crop per drop. Water use is expressed either in terms of delivery to a use, or depletion by a use through evapotranspiration, pollution, or directing water to a sink where it cannot be reused. Improving physical water productivity is important to reduce future water needs in agriculture.

Economic water productivity relates the value of agricultural production to agricultural water use. A holistic assessment should account for the benefits and costs of water, including less tangible livelihood benefits, but this is rarely done. Improving economic water productivity is important for economic growth and poverty reduction.

Annex D
Acronyms, Abbreviations and Units

AARINENA	Association of Agricultural Research Institutions in the Near East and North Africa
AATF	African Agricultural Technology Foundation
ACP-EU	African, Caribbean and Pacific- European Union
ADB	African Development Bank
AEC	African Economic Community
AEO	Africa Environmental Outlook
AFPLAN	Regional Food Plan for Africa
AGRA	Alliance for a Green Revolution for Africa
AIDS	Acquired immune deficiency syndrome
AIRD	Inter-institutions and Universities Agency for Research on Development
AKIS	agriculture knowledge and information system
AKST	Agricultural knowledge, science and technology
AML	African model law
AMIS	Agricultural market information systems
AMU	Arab Megreb Union
ANADER	Agence Nationale du Développement Rural
ARC	Agricultural Research Council
ARI	agricultural research institute
ARIPO	African Regional Intellectual Property Organization
ASARECA	Association for Strengthening of Agricultural Research in Eastern and Central Africa
ASF	African Swine Fever
ASP	Africa Stockpiles Programme
AU	African Union
AU-IBAR	AU InterAfrican Bureau of Animal Resources
BMZ	German Federal Ministry for Economic Cooperation and Development
BNF	Biological nitrogen fixation
BSE	Bovine spongiform encephalopathy
billion	one thousand million
BRICS	Biotechnology regional innovation centers
Bt	soil bacterium (usually refers to plants made insecticidal using a variant of various toxin genes sourced from plasmids of these bacteria)
CAP	Common Agricultural Policy
CAADP	Comprehensive Africa Agriculture Development Program
CBD	Convention on Biological Diversity
C	carbon
CA	Comprehensive Assessment of Water Management in Agriculture
CAMPFIRE	Communal Areas Management Programme for Indigenous Resources
CARENSA	Cane Resources Network for Southern Africa
CBD	Convention on Biological Diversity
CBO	Community-based organization
CBPP	contagious bovine pleuropneumonia
CDD	Community driven development
CDM	Clean Development Mechanism
CEMAC	Economic and Monetary Community of Central Africa
CGAP	Consultative Group to Assist the Poor
CGIAR	Consultative Group on International Agricultural Research
CH_4	methane
CIAL	Comité de Investigación Agrícola Local (Local Agricultural Research Committee)
CIAT	International Center for Tropical Agriculture
CIF	Cost, insurance and freight
CIFOR	Center for International Forestry Research
CIHEAM	International Center for Advanced Mediterranean Agronomic Studies
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CIRAD	Centre de Cooperation Internationale en Agronomique pour le Developpement (Agriculture Research for Developing Countries)
CIS	Commonwealth of Independent States among Central Asia and Caucasus countries
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flor
CLAES	Central Laboratory for Agricultural Expert Systems

C:N	carbon to nitrogen ratio
CNRA	Centre National de Recherche Agricole
CO_2	carbon dioxide
COA	certified organic agriculture
Codex	Codex Alimentarius
COMESA	Common Market for East and Southern Africa
COMIFAC	Conference of Ministers in charge of Forests in Central Africa
CORAF	Conseil quest et Centre Africain pour la recherché et le developpement agricole (West and Central African Council for Agricultural Research and Development)
CPB	Cartagena Protocol on Biosafety
CPWF	Challenge Program on Water for Food
CSO	civil society organization
CWANA	Central and West Asia and North Africa
Defra	UK Department of Environment, Food and Rural Affairs
DFID	UK Department of International Development
DNA	deoxyribonucleic acid
DRC	Democratic Republic of Congo
EASCOM	East Africa Seed Committee
EASSy	East Africa Submarine Cable System
ECCAS	Economic Community of Central African States
ECF	East Coast Fever
ECOWAS	Economic Community of West African States
EJ	Exajoule
ENSO	El Niño Southern Oscillation
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FARA	Forum for Agricultural Research in Africa
Fe	iron
FFS	farmer field school
FLO	Fair Trade Labeling Organization
FMD	foot and mouth disease
FPRE	Farmer participatory research and extension
FSRE	Farming systems research and extension
g	gram (10^{-3} kg)
GAP	Good Agricultural Practices
GATT	General Agreement on Trade and Tariffs
GBA	Global Biodiversity Assessment
GDP	Gross domestic product
GE	genetic engineering/genetically engineered
GEF	Global Environment Facility
GEO	Global Environment Outlook
GEWEX	Global Energy and Water Experiment
Gg	gigagram (10^6 kg)
Gha	gigahectare (10^9 hectare)
GHG	greenhouse gas
GIS	geographic information system
GLASOD	Global assessment of human-induced soil degradation
GM	genetically modified/genetic modification
GMO	genetically modified organism
GNP	Gross National Product
GPS	global positioning system
GREP	global rinderpest eradication program
GTZ	German Agency for Technical Cooperation
GURT	Genetic Use Restriction Technologies
ha	hectare (10^4 m^2)
HACCP	Hazard Analysis Critical Control Point
HIV	Human immunodeficiency virus
HT	herbicide tolerant
HYV	High yielding variety
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
IAC	InterAcademy Council
IAEA	International Atomic Energy Agency
IARC	International Agricultural Research Center
IAS	invasive alien species
IBRD	International Bank of Rural Development
ICARDA	International Center for Agricultural Research in the Dry Areas
ICM	integrated crop management
ICRAF	World Agroforestry Center
ICRISAT	International Crops Research Institute for Semi-arid Tropics
ICT	information and communication technologies
IDA	International Development Agency
IDRC	International Development Research Center (Canada)
IEA	International Energy Agency
IFAD	International Fund for Agricultural Development
IFC	International Finance Corporation
IFI	international financial institution
IFOAM	International Federation of Organic Agriculture Movements
IFPRI	International Food Policy Research Institute
IITA	International Institute for Tropical Agriculture
IK	Indigenous knowledge
ILH	improved land husbandry
ILO	International Labour Organisation
ILRI	International Livestock Research Institute
IMF	International Monetary Fund
INM	Integrated Nutrient Management
INRM	Integrated Natural Resources Management
IP	intellectual property
IPCC	Intergovernmental Panel on Climate Change
IPGRI	Bioversity International

IPM Integrated pest management
IPPC International Plant Protection Convention
IPPM Integrated production and pest management
IPR intellectual property rights
IRD Institut de recherche pour le développement (French Research Institute for Development)
IRRI International Rice Research Institute
ISFM integrated soil fertility management
ISP Internet service providers
IUCN World Conservation Union
IWMI International Water Management Institute
IWRM Integrated water resources management
IXP Internet exchange points
K potassium
kcal kilocalorie
kg kilogram, 10^3 grams
km kilometer
kWh kilowatt hour
LAC Latin America and the Caribbean
LDC least developed countries
LEISA Low-External Input Sustainable Agriculture
LIC low income country
LINKS Local and Indigenous Knowledge Systems
LPG liquified petroleum gas
LUC land use change
m 10^2 cm
MA Millennium Ecosystem Assessment
MAB/S marker assisted breeding/selection
MAPP Multi-Country Agricultural Productivity Program
MDG Millennium Development Goals
Mg magnesium
mg milligram (10^{-3} grams)
MIGA Multilateral Investment Agency
MNC multinational corporation
MRL maximum residue level
N nitrogen
NAE North America and Europe
NAFTA North American Free Trade Agreement
NARI National agricultural research institute
NARS National agricultural research systems
NASSP National Agricultural Services Support Program
NBF National Biosafety Frameworks
NBSAP National Biodiversity Strategy and Action Plans
ND Newcastle Disease
NEPAD New Partnership for Africa's Development
ng nanogram (10^{-9} grams)
NGO nongovernmental organization
N_2O nitrous oxide
NPK nitrogen, phosphorus, potassium
NRM Natural resource management
NTFP non-timber forest product
NUE nitrogen use efficiency
NWFP Non-wood forest products
OA organic agriculture
ODA overseas development assistance
OECD Organization of Economic Cooperation and Development
OH hydroxyl
OIE World Organization for Animal Health
ORSTOM now IRD—Institut de recherche pour le développement
OSS Sahel and Sahara Observatory
P phosphorus
PAAT Program against African Trypanosomiasis
PADETES Participatory Demonstration and Training Extension Program
PAN Pesticide Action Network
PASS Program for African Seed Systems
PATTEC Pan African Tsetse and Trypanosomiasis Eradication Campaign
PEM Protein energy malnutrition
PES Payments for environmental/ecosystem services
PFM Participatory forest management
PGRFA Plant Genetic Resources for Food and Agriculture
PIPRA Public-Sector Intellectual Property Resource for Agriculture
PPB Participatory plant breeding
ppm parts per million
ppmv parts per million by volume
PPP Purchasing Power Parity
PPQ plant protection and quarantine
PVP plant variety protection
PVT preliminary varietal trials
R&D research and development
REC Regional economic community
ROR rates of return
RVF Rift Valley Fever
S&T science and technology
SADC Southern African Development Community
SAP Structural adjustment program
SGRP System-wide Genetic Resource Program
SIA Strategic Impact Assessment
SME Small and medium enterprises
SMS short message service
SPS Sanitary and phytosanitary
SRES Special Report on Emission Scenarios
SRI System of Rice Intensification
SSA Sub-Saharan Africa

SWC soil and water conservation
TB tuberculosis
TBD tick-borne diseases
TK traditional knowledge
TNC transnational corporations
tonne 10^3 kg (metric ton)
TRIPS Trade-Related Aspects of Intellectual Property Rights
T&V training and visit
TV Traditional variety
UAE United Arab Emirates
UEMOA Economic and Monetary Union of West Africa
UNCBD UN Convention on Biodiversity
UNCCD UN Commission to Combat Desertification
UNCED UN Conference on Environment and Development
UNCTAD UN Conference on Trade and Development
UNDP United Nations Development Program
UNECA United Nations Economic Commission for Africa
UNEP United Nations Environment Programme
UNESCO United Nations Educational, Scientific and Cultural Organization
UNFCCC United Nations Framework Convention on Climate Change
UNWWAP United Nations World Water Assessment Programme
UPOV International Union for the Protection of New Varieties of Plants
USAID US Agency for International Development
USDA US Department of Agriculture
WAPP West Africa Agricultural Productivity Program
WARDA West African Rice Development Authority or Africa Rice Center
WASNET West Africa Seed Network
WCED World Commission on Environment and Development (Brundtland Commission)
WEDO Women's Environment and Development Organization
WHO World Health Organization
WIPO World Intellectual Property Organization
WMO World Meteorological Organization
WP water productivity
WRI World Resources Institute
WSSD World Summit on Sustainable Development
WTO World Trade Organization
WUA Water User Association
WUE water use efficiency
WWF World Wildlife Fund
yr year
Zn zinc

Annex E

Secretariat and Cosponsor Focal Points

Secretariat

World Bank

Marianne Cabraal, Leonila Castillo, Jodi Horton, Betsi Isay, Pekka Jamsen, Pedro Marques, Beverly McIntyre, Wubi Mekonnen, June Remy

UNEP

Marcus Lee, Nalini Sharma, Anna Stabrawa

UNESCO

Guillen Calvo

With special thanks to the Publications team: Audrey Ringler (logo design), Pedro Marques (proofing and graphics), Ketill Berger and Eric Fuller (graphic design)

Regional Institutes

Sub-Saharan Africa – African Centre for Technology Studies (ACTS)

Ronald Ajengo, Elvin Nyukuri, Judi Wakhungu

Central and West Asia and North Africa – International Center for Agricultural Research in the Dry Areas (ICARDA)

Mustapha Guellouz, Lamis Makhoul, Caroline Msrieh-Seropian, Ahmed Sidahmed, Cathy Farnworth

Latin America and the Caribbean – Inter-American Institute for Cooperation on Agriculture (IICA)

Enrique Alarcon, Jorge Ardila Vásquez, Viviana Chacon, Johana Rodríguez, Gustavo Sain

East and South Asia and the Pacific – WorldFish Center

Karen Khoo, Siew Hua Koh, Li Ping Ng, Jamie Oliver, Prem Chandran Venugopalan

Cosponsor Focal Points

GEF	Mark Zimsky
UNDP	Philip Dobie
UNEP	Ivar Baste
UNESCO	Salvatore Arico, Walter Erdelen
WHO	Jorgen Schlundt
World Bank	Mark Cackler, Kevin Cleaver, Eija Pehu, Juergen Voegele

Annex F

Steering Committee for Consultative Process and Advisory Bureau for Assessment

Steering Committee

The Steering Committee was established to oversee the consultative process and recommend whether an international assessment was needed, and if so, what was the goal, the scope, the expected outputs and outcomes, governance and management structure, location of the secretariat and funding strategy.

Co-chairs

Louise Fresco, Assistant Director General for Agriculture, FAO
Seyfu Ketema, Executive Secretary, Association for Strengthening Agricultural Research in East and Central Africa (ASARECA)
Claudia Martinez Zuleta, Former Deputy Minister of the Environment, Colombia
Rita Sharma, Principal Secretary and Rural Infrastructure Commissioner, Government of Uttar Pradesh, India
Robert T. Watson, Chief Scientist, The World Bank

Nongovernmental Organizations

Benny Haerlin, Advisor, Greenpeace International
Marcia Ishii-Eiteman, Senior Scientist, Pesticide Action Network North America Regional Center (PANNA)
Monica Kapiriri, Regional Program Officer for NGO Enhancement and Rural Development, Aga Khan
Raymond C. Offenheiser, President, Oxfam America
Daniel Rodriguez, International Technology Development Group (ITDG), Latin America Regional Office, Peru

UN Bodies

Ivar Baste, Chief, Environment Assessment Branch, UN Environment Programme
Wim van Eck, Senior Advisor, Sustainable Development and Healthy Environments, World Health Organization
Joke Waller-Hunter, Executive Secretary, UN Framework Convention on Climate Change
Hamdallah Zedan, Executive Secretary, UN Convention on Biological Diversity

At-large Scientists

Adrienne Clarke, Laureate Professor, School of Botany, University of Melbourne, Australia
Denis Lucey, Professor of Food Economics, Dept. of Food Business & Development, University College Cork, Ireland, and Vice-President NATURA
Vo-tong Xuan, Rector, Angiang University, Vietnam

Private Sector

Momtaz Faruki Chowdhury, Director, Agribusiness Center for Competitiveness and Enterprise Development, Bangladesh
Sam Dryden, Managing Director, Emergent Genetics
David Evans, Former Head of Research and Technology, Syngenta International
Steve Parry, Sustainable Agriculture Research and Development Program Leader, Unilever
Mumeka M. Wright, Director, Bimzi Ltd., Zambia

Consumer Groups

Michael Hansen, Consumers International
Greg Jaffe, Director, Biotechnology Project, Center for Science in the Public Interest
Samuel Ochieng, Chief Executive, Consumer Information Network

Producer Groups

Mercy Karanja, Chief Executive Officer, Kenya National Farmers' Union
Prabha Mahale, World Board, International Federation Organic Agriculture Movements (IFOAM)
Tsakani Ngomane, Director Agricultural Extension Services, Department of Agriculture, Limpopo Province, Republic of South Africa
Armando Paredes, Presidente, Consejo Nacional Agropecuario (CNA)

Scientific Organizations

Jorge Ardila Vásquez, Director Area of Technology and Innovation, Inter-American Institute for Cooperation on Agriculture (IICA)
Samuel Bruce-Oliver, NARS Senior Fellow, Global Forum for Agricultural Research Secretariat
Adel El-Beltagy, Chair, Center Directors Committee, Consultative Group on International Agricultural Research (CGIAR)
Carl Greenidge, Director, Center for Rural and Technical Cooperation, Netherlands
Mohamed Hassan, Executive Director, Third World Academy of Sciences (TWAS)
Mark Holderness, Head Crop and Pest Management, CAB International
Charlotte Johnson-Welch, Public Health and Gender Specialist and Nata Duvvury, Director Social Conflict and Transformation Team, International Center for Research on Women (ICRW)
Thomas Rosswall, Executive Director, International Council for Science (ICSU)
Judi Wakhungu, Executive Director, African Center for Technology Studies

Governments

Peter Core, Director, Australian Centre for International Agricultural Research
Keming Qian, Director General Inst. Agricultural Economics, Dept. of International Cooperation, Chinese Academy of Agricultural Science
Tiina Huvio, Senior Advisor, Agriculture and Rural Development, Ministry of Foreign Affairs
Alain Derevier, Senior Advisor, Research for Sustainable Development, Ministry of Foreign Affairs
Germany: Hans-Jochen de Haas, Head, Agricultural and Rural Development, Federal Ministry of Economic Cooperation and Development (BMZ)
Zoltan Bedo, Director, Agricultural Research Institute, Hungarian Academy of Sciences
Aidan O'Driscoll, Assistant Secretary General, Department of Agriculture and Food
Hamid Narjisse, Director General, INRA
Eugenia Serova, Head, Agrarian Policy Division, Institute for Economy in Transition
Grace Akello, Minister of State for Northern Uganda Rehabilitation
Paul Spray, Head of Research, DFID
Rodney Brown, Deputy Under Secretary of Agriculture and Hans Klemm, Director of the Office of Agriculture, Biotechnology and Textile Trade Affairs, Department of State

Foundations and Unions

Susan Sechler, Senior Advisor on Biotechnology Policy, Rockefeller Foundation
Achim Steiner, Director General, The World Conservation Union (IUCN)
Eugene Terry, Director, African Agricultural Technology Foundation

Advisory Bureau

Non-government Representatives

Consumer Groups
Jaime Delgado • Asociación Peruana de Consumidores y Usuarios
Greg Jaffe • Center for Science in the Public Interest
Catherine Rutivi • Consumers International
Indrani Thuraisingham • Southeast Asia Council for Food Security and Trade
Jose Vargas Niello • Consumers International Chile

International organizations
Nata Duvvury • International Center for Research on Women
Emile Frison • CGIAR
Mohamed Hassan • Third World Academy of Sciences
Mark Holderness • GFAR
Jeffrey McNeely • World Conservation Union (IUCN)
Dennis Rangi • CAB International
John Stewart • International Council of Science (ICSU)

NGOs
Kevin Akoyi • Vredeseilanden
Hedia Baccar • Association pour la Protection de l'Environment de Kairouan
Benedikt Haerlin • Greenpeace International
Juan Lopez • Friends of the Earth International
Khadouja Mellouli • Women for Sustainable Development
Patrick Mulvaney • Practical Action
Romeo Quihano • Pesticide Action Network
Maryam Rahmaniam • CENESTA
Daniel Rodriguez • International Technology Development Group

Private Sector
Momtaz Chowdhury • Agrobased Technology and Industry Development
Giselle L. D'Almeida • Interface
Eva Maria Erisgen • BASF
Armando Paredes • Consejo Nacional Agropecuario
Steve Parry • Unilever
Harry Swaine • Syngenta (resigned)

Producer Groups
Shoaib Aziz • Sustainable Agriculture Action Group of Pakistan
Philip Kiriro • East African Farmers Federation
Kristie Knoll • Knoll Farms
Prabha Mahale • International Federation of Organic Agriculture Movements
Anita Morales • Apit Tako
Nizam Selim • Pioneer Hatchery

Government Representatives

Central and West Asia and North Africa
Egypt • Ahlam Al Naggar
Iran • Hossein Askari
Kyrgyz Republic • Djamin Akimaliev
Saudi Arabia • Abdu Al Assiri, Taqi Elldeen Adar, Khalid Al Ghamedi
Turkey • Yalcin Kaya, Mesut Keser

East/South Asia/Pacific
Australia • Simon Hearn
China • Puyun Yang
India • PK Joshi
Japan • Ryuko Inoue
Philippines • William Medrano

Latin America and Caribbean
Brazil • Sebastiao Barbosa, Alexandre Cardoso, Paulo Roberto Galerani, Rubens Nodari
Dominican Republic • Rafael Perez Duvergé
Honduras • Arturo Galo, Roberto Villeda Toledo
Uruguay • Mario Allegri

North America and Europe
Austria • Hedwig Woegerbauer
Canada • Iain MacGillivray
Finland • Marja-Liisa Tapio-Bistrom
France • Michel Dodet
Ireland • Aidan O'Driscoll, Tony Smith
Russia • Eugenia Serova, Sergey Alexanian
United Kingdom • Jim Harvey, David Howlett, John Barret
United States • Christian Foster

Sub-Saharan Africa
Benin • Jean Claude Codjia
Gambia • Sulayman Trawally
Kenya • Evans Mwangi
Mozambique • Alsácia Atanásio, Júlio Mchola
Namibia • Gillian Maggs-Kölling
Senegal • Ibrahim Diouck

Index

Page references followed by *f*, *t*, and *b* indicate figures, tables, and boxes, respectively.

About Island Press

Since 1984, the nonprofit Island Press has been stimulating, shaping, and communicating the ideas that are essential for solving environmental problems worldwide. With more than 800 titles in print and some 40 new releases each year, we are the nation's leading publisher on environmental issues. We identify innovative thinkers and emerging trends in the environmental field. We work with world-renowned experts and authors to develop cross-disciplinary solutions to environmental challenges.

Island Press designs and implements coordinated book publication campaigns in order to communicate our critical messages in print, in person, and online using the latest technologies, programs, and the media. Our goal: to reach targeted audiences—scientists, policymakers, environmental advocates, the media, and concerned citizens—who can and will take action to protect the plants and animals that enrich our world, the ecosystems we need to survive, the water we drink, and the air we breathe.

Island Press gratefully acknowledges the support of its work by the Agua Fund, Inc., Annenberg Foundation, The Christensen Fund, The Nathan Cummings Foundation, The Geraldine R. Dodge Foundation, Doris Duke Charitable Foundation, The Educational Foundation of America, Betsy and Jesse Fink Foundation, The William and Flora Hewlett Foundation, The Kendeda Fund, The Andrew W. Mellon Foundation, The Curtis and Edith Munson Foundation, Oak Foundation, The Overbrook Foundation, the David and Lucile Packard Foundation, The Summit Fund of Washington, Trust for Architectural Easements, Wallace Global Fund, The Winslow Foundation, and other generous donors.

"Although considered by many to be a success story, the benefits of productivity increases in world agriculture are unevenly spread. Often the poorest of the poor have gained little or nothing; and 850 million people are still hungry or malnourished with an additional 4 million more joining their ranks annually. We are putting food that appears cheap on our tables; but it is food that is not always healthy and that costs us dearly in terms of water, soil and the biological diversity on which all our futures depend."

—Professor Bob Watson, director, IAASTD

The International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD), on which *Agriculture at the Crossroads* is based, was a three-year collaborative effort begun in 2005 that assessed our capacity to meet development and sustainability goals of:

- Reducing hunger and poverty
- Improving nutrition, health and rural livelihoods
- Facilitating social and environmental sustainability

Governed by a multi-stakeholder bureau comprised of 30 representatives from government and 30 from civil society, the process brought together 110 governments and 400 experts, representing non-governmental organizations (NGOs), the private sector, producers, consumers, the scientific community, multilateral environment agreements (MEAs), and multiple international agencies involved in the agricultural and rural development sectors.

In addition to assessing existing conditions and knowledge, the IAASTD uses a simple set of model projections to look at the future, based on knowledge from past events and existing trends such as population growth, rural/urban food and poverty dynamics, loss of agricultural land, water availability, and climate change effects.

This set of volumes comprises the findings of the IAASTD. It consists of a *Global Report*, a brief *Synthesis Report*, and 5 subglobal reports. Taken as a whole, the IAASTD reports are an indispensable reference for anyone working in the field of agriculture and rural development, whether at the level of basic research, policy, or practice.

IAASTD
International Assessment of Agricultural Knowledge, Science and Technology for Development

Cover design by Linda McKnight, McKnight Design, LLC
Cover photo by Mark Edwards/Peter Arnold, Inc.

UNDP · UNEP · UNESCO · THE WORLD BANK · WHO · GLOBAL ENVIRONMENT FACILITY

ISBN 13: 978-1-59726-541-6
ISBN 10: 1-59726-541-1

ISLANDPRESS

Washington • Covelo • London
www.islandpress.org

All Island Press books are printed on recycled, acid-free paper.