INTERNATIONAL ASSESSMENT OF AGRICULTURAL KNOWLEDGE, SCIENCE AND TECHNOLOGY FOR DEVELOPMENT: SUMMARY FOR DECISION MAKERS OF THE SUB-SAHARAN AFRICA REPORT

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ANNEXES

From Agriculture at a Crossroads: Sub-Saharan Africa, by the IAASTD.

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 Töpfer, 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 interrelated 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 Multi-Donor 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 Regional 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.

Co-chairs
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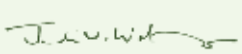

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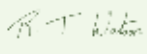

STATEMENT BY GOVERNMENTS

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 multi-stakeholder 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 fulfils 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 approve the sub-Saharan Africa Summary for Decision Makers:

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).

BACKGROUND

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 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, Kenya, in September 2004 that an international assessment of the role of agricultural knowledge, science and technology 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 Science and Technology for Development (IAASTD) was endorsed as a multi-thematic, multi-spatial, multi-temporal intergovernmental process with a multi-stakeholder Bureau cosponsored by the Food and Agricultural Organization of the United Nations (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 multi-stakeholder 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 five 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 multi-functionality 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 of agricultural and other natural resources. Agricultural knowledge, science and technology 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 agricultural knowledge, science and technology.

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 agricultural knowledge, science and technology system to improve the situation for poor rural people, especially small-scale farmers, rural labourers 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 multi-disciplinary and multi-stakeholder 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 agricultural knowledge, science and technology and points towards a range of 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 world views; 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); sub-Saharan Africa (SSA). It (i) assesses the generation, access, dissemination and use of public and private sector agricultural knowledge, science and technology in relation to the goals, using local, traditional and formal knowledge; (ii) analyse existing and emerging technologies, practices, policies and institutions and their impact on the goals; (iii) 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 agricultural knowledge, science and technology to meet the goals; (iv) 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 (v) identifies options for future public and private investments in agricultural knowledge, science and technology. In addition, the IAASTD will enhance local and regional capacity to design, implement and utilize similar assessments.

In this assessment agriculture is used in the widest sense to include production of food, feed, fuel, fibre 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 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 Johannesburg, South Africa 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 agricultural knowledge, science and technology, the institutional dimensions and the multi-functionality 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 (2007); IFPRI Global Hunger Indices (yearly); and World Bank Internal Report of Investments in sub-Saharan Africa (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, the European Commission, and CropLife International. 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 have a different set of priorities and responsibilities and operate in different socio-economic-political circumstances.

IAASTD SUB-SAHARAN AFRICA REPORT: SUMMARY FOR DECISION MAKERS

Agriculture, which incorporates crops, forests, fisheries, livestock and agroforestry, accounts for an average of 32 percent of the region's GDP, and is woven into the fabric of most societies and cultures in the region. Even though the population is growing and rapidly urbanizing, most families will continue to have ties to land and water.

Agricultural knowledge, science and technology (AKST) has had some notable successes in sub-Saharan Africa including the widespread adoption of improved crop and tree varieties and livestock breeds; the development of pest-resistant and drought-tolerant varieties; biocontrol of pests and parasites such as cassava mealybug, green mite and ticks; integrated natural resource management; development of biodiversity products; and methods and tools for improved productivity and management in water availability for crops, livestock, fodder, trees and fisheries. Yet in sub-Saharan Africa, unlike in other regions, overall per capita agricultural yields declined from 1970 to 1980 and since then have stagnated. The number of

poor people is increasing, 30 percent of the population lives with chronic hunger, and similar levels of malnutrition in children under the age of five persist.

Increasing agricultural productivity remains a priority for sub-Saharan Africa, given the very low yields in the region and widespread hunger, poverty and malnutrition. However, the development and sustainable goals of reducing hunger, achieving food security, improving health and nutrition, and increasing environmental and social sustainability will only be reached if the focus of agriculture and agricultural knowledge, science and technology moves away from simply the production of food, fibre, feed, and bioenergy. A broader perspective encompasses an integrated agricultural commodity value chain from production through to processing and marketing with a local and regional perspective. It accounts for the multiple functions of agriculture that include the improvement of livelihoods, the enhancement of environmental services, the conservation of natural resources and biodiversity, and the contribution of agriculture to the maintenance of social and cultural traditions. It recognizes that women, who account for approximately 70 percent of agricultural workers and 80 percent of food processors in sub-Saharan Africa, need significantly increased representation in research, extension and policy making, and equitable access to education, credit and secure land tenure. It also recognizes the need for higher quality education, research and extension that addresses the development and sustainability goals.

Challenges and Options

Current low levels of agricultural productivity in sub-Saharan Africa prevent much of the population from escaping poverty, hunger and malnutrition. On average, livestock and crop yields in sub-Saharan Africa are lower than all other regions, though these averages mask considerable variation. Cereal yields, for example, range from 185 kg ha^{-1} in Botswana to 2,100 kg ha^{-1} in Cameroon. Low yields have been difficult to overcome because they are the result of a wide range of agronomic, environmental, institutional, social and economic factors.

Low input use, including total fertilizer input of less than 10 kg ha^{-1} on average, contributes to sub-Saharan Africa's low crop yields. Although there is considerable variation across farming systems and countries, in the mid-1990s every country in sub-Saharan Africa was estimated to have a negative soil nutrient balance for nitrogen, potassium and phosphorus. Increased fertilizer use is seen by most practitioners as essential, reflected in the resolution by African Union members to reduce costs through national and regional level procurement, harmonization of taxes and regulations, the elimination of taxes and tariffs, and improving access to fertilizer, output market incentives, and credit from input suppliers. The cost of fertilization can also be reduced directly through fertilizer subsidies. These are currently being implemented in some sub-Saharan Africa countries to support farmers. The cost of fertilization can also be reduced through the intensified use of organic fertilizer.

Agrochemicals, especially some synthetic fertilizers and pesticides, have caused negative effects on human and animal health and the environment in some parts of sub-Saharan Africa; this has been exacerbated by unsafe application processes and inadequate access to information concerning handling and disposal practices. Pollution, particularly with respect to water bodies, may also result from inappropriate use. The economic, environmental and health costs associated with greater use of agrochemicals suggest that agricultural knowledge, science and technology options involve reorienting research away from high-input blanket doses towards technologies that enable technically efficient applications specific to local soil conditions and towards integrated nutrient management approaches.

More than four-fifths of agricultural land is affected by soil moisture stress that limits the uptake of nutrients, implying the need to conserve both water and soil organic matter in parallel. Current efforts to improve soil fertility and regenerate the land include research into integrated soil fertility management that builds on farmer practices such as improved natural fallows, rotations, mixed livestock-cropping systems and incorporation of green and livestock manures where available. The adoption of animal manure is limited by transport costs, the quantity needed per unit area of land and labour costs of weeding. Green manures help to revive

degraded land, but often compete with food and cash crops, and the benefits are often unnoticed in the short run. These are the types of tradeoffs that agricultural knowledge, science and technology needs to evaluate and minimize with farmers. Organic, agroforestry and no- or low-till farming offer integrated agro-ecological approaches to reducing soil degradation, but further studies are required to determine the conditions and incentives required for farmers to adopt these methods.

Increases in the exploitation of both surface and groundwater are required for sub-Saharan Africa to increase productivity. Agricultural production in sub-Saharan Africa is predominantly rainfed. Only 4 percent of agricultural land is irrigated compared to 37 percent in Asia and 15 percent in Latin America. This situation is exacerbated by high rainfall variability and uncertainty, especially in arid and semiarid areas, and projected rising temperatures in sub-Saharan Africa and decreased precipitation in the Sahel and southern Africa as a consequence of climate change. The characteristics of agriculture in sub-Saharan Africa suggest that smaller-scale irrigation, 'greenwater' technologies such as water conservation, rainwater harvesting and community level water management need to be explored as alternatives to large-scale irrigation projects. Increases in the level of irrigation can come from both surface and ground water, drawing lessons from within and outside the region on viable small to medium scale irrigation techniques that require limited infrastructural development and can reach many farmers. Methods such as pumping from the rivers on an individual and small group basis, and locally manufactured drip systems are still to be fully exploited.

Efficient and equitable water allocation, a component of agricultural knowledge, science and technology, requires a better understanding of the value of water for different competing users, appropriate mechanisms for allocating water, (e.g. pricing, allocation of property rights, regulation) and negotiations that create incentives for farmers to adopt water-efficient technologies. The appropriate approach will require integrated research that builds on local knowledge, existing technologies, existing water institutions and the ability to enforce rights through

formal systems, and also on complementary institutions such as land rights and farmers' access to credit. Poor households may simply not be able to afford water priced at its true cost, in which case approaches such as that taken in South Africa (households get a free allocation per month) need to be explored.

Increasing the performance of agriculture requires an improvement in productivity on the 80 percent of sub-Saharan Africa farms that are smaller than two hectares. Earlier paradigms that typically attempted to fit farmers into the existing linear top-down structures of research-development-extension worked relatively well for major cash crops, but there has been less success on small-scale diversified farms. Options for agricultural knowledge, science and technology include integrated and participatory approaches that can increase the likelihood that appropriate technologies for production are developed and adopted by small-scale farmers. Alternative approaches include moving farmer engagement closer to priority setting and funding decisions, increasing collaboration with social scientists, and increasing participatory and interdisciplinary work in the core research institutions. There is evidence from East Africa that innovative approaches to agricultural knowledge, science and technology development such as farmer research groups are more successful in reaching women farmers than traditional extension activities. By understanding farmers' contexts and priorities, grounding new technologies in an understanding of farmers' motivations and constraints, and explicitly including groups that are often socially excluded such as women and minorities, agricultural knowledge, science and technology is more likely to be relevant and adopted.

Many farmers in sub-Saharan Africa use indigenous animal breeds which are able to withstand harsh conditions and tolerate many diseases, but their meat, milk and egg productivity is low. Options for agricultural knowledge, science and technology to improve livestock productivity include the use of open nucleus breeding schemes and improving the genetic potential of indigenous breeds, e.g. through characterizing genetic diversity in order to provide insights into genetic relationships. Given that animal disease management is one of the key explanations

for movements, herd size and growth, agricultural knowledge, science and technology has a role to play in addressing the impact of disease at the smallholder level.

Scaling up integrated approaches is difficult because successful innovations tend to incorporate local knowledge and to be specific to the particular agro-climatic conditions. Public good aspects of baskets of prototype technologies, whether originating from farmers, researchers or collaborative efforts, that match the diversity of farmers' fields can be transferred with appropriate scaling up and dissemination strategies. Where current structures are ineffective, new institutional and organizational arrangements may be required to support the empowerment of local communities to develop, adapt and disseminate agricultural knowledge, science and technology. Despite the increasing use of participatory and integrated approaches to agricultural knowledge, science and technology development, institutional resources still tend to be compartmentalized. For example, water management is often undertaken independently of pest, soil, livestock and forest management. Reduced water availability is the main cause of loss of productivity in more than half of the grazing land. Improved water management would improve livestock health through quantity and quality of grazing resources and reduced walking distance to watering points.

Knowledge, understanding and uptake of new agricultural technologies on the whole are poor and patchy in sub-Saharan Africa. In the IAASTD assessment, biotechnology is defined according to that in the Convention on Biological Diversity. In this context it includes much of the traditional knowledge and many of the traditional technologies used in sub-Saharan Africa for the production, processing and preservation of food plus modern molecular tools such as genetic engineering, marker assisted selections or breeding and genomic techniques. In this broader sense biotechnology, as an agricultural knowledge, science and technology subset, has a role to play in addressing development and sustainability goals but it needs to be managed to avoid derivative problems from its use.

Genetic engineering is considered by some to have important ramifications for productivity but some of its uses and impacts are hotly contested. Contamination of farmer-saved seed and threats to biodiversity in centers of origin are key concerns with respect to biotechnology and genetic engineering in particular. The environmental risks and evidence of negative health impacts mean that sub-Saharan Africa's ability to make informed decisions regarding biotechnology research, development, delivery and application is critical. In part, the current limited capacity of individual countries to address risk assessment and management of transgenics is being addressed through regional capacity building and harmonization of guidelines, policies, legislation and creating an understanding of biosafety issues. However, individual countries could develop and advance their own biotechnology capacities. The development of comprehensive national biosafety frameworks must work in conjunction with effective enforcement institutions and implementation mechanisms.

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 where staple and important crops have been saved by biological control over wide areas. There are a number of economic assessments showing biocontrol's successes including coffee mealybug and more recently the campaigns against cassava mealybug, green mite and water hyacinth that show large and accruing gains. These controls are still in place and contribute to small farmers' food security in the long term.

Sub-Saharan Africa countries are the most intense users of biomass in the world, meeting more than 50 percent of their total primary energy consumption from this source. This biomass energy 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. Agricultural knowledge, science and technology has played a role in improving the traditional bioenergy technologies,

such as design and supply of fuel-efficient cooking stoves, and helping people to move to more sustainable, efficient and less harmful forms of energy. Some sub-Saharan Africa countries have realized this potential and have programs for the cogeneration of electricity.

R&D in improving biofuel yields per unit of land and in reducing economic costs of production are needed. Biofuel production involves tradeoffs that have not yet been evaluated. Globally, output from first generation biofuels produced from agricultural crops is growing rapidly supported by government policies, but these fuels are rarely economically competitive with petroleum fuels. The production of first generation biofuels in particular in sub-Saharan Africa is likely to put pressure on forests and marginal lands. A major debate centres around whether this use of biomass will remove land from production of food crops and/or result in increased prices of staple commodities, such as maize, if used for biofuels. Next generation biofuels may have greater potential for sub-Saharan Africa. Many use residues, stems and leaves and so could reduce pressure on land requirements, but concerns remain, e.g. over the environmental impact of harvesting agricultural residues. Agricultural knowledge, science and technology has a large role to play concerning the careful analysis of biofuel technology appropriate for sub-Saharan Africa, in parallel with the development of policies and capacity building to reduce the negative effects of growing biofuels and determine the health, environmental, energy and food security tradeoffs in the region. Increased research will also enable sub-Saharan Africa countries to determine their appropriate entry points.

Rapid depletion of sub-Saharan Africa's natural resources and the genetic erosion of indigenous germplasm threaten the sustainability of agriculture in sub-Saharan Africa. Land use change, including deforestation and expansion of agriculture into marginal areas, results in nutrient and biodiversity losses, water and soil degradation, loss of pasture, adversely affects ground and surface water availability and reduces the resilience of agricultural systems, especially in semiarid regions.

These issues affect every aspect of agricultural knowledge, science and technology as environmental degradation affects the productivity and sustainability of agriculture. Over-exploitation of freshwater and oceanic fisheries, controlled breeding and the development of livestock, crop and tree breeds with a narrow genetic base further threaten the resource base.

Integrated natural resource management options include diversifying farming systems, enhancing natural capital and building on local and traditional knowledge. For instance, significant investments have been made in the development of high value products from indigenous plant species for the pharmaceutical, neutraceutical and cosmetic industries. Such localization approaches place agriculture squarely in the context of society and ecosystems and so can empower local communities to address depletion of natural resources and loss of biodiversity, in conjunction with combating poverty and improving food security. Integrated approaches allow the generation of substantive knowledge concerning the trade-offs among economic, social, cultural and ecological goals, the roles of various actors such as producers, the private sector, civil society and government, and can accommodate new challenges such as changes caused by climate change, including the increased problem of invasive species. These sets of activities and interventions will not reach system level goals without an explicit analysis of who wins and who loses and how the potential tradeoffs and synergies will be managed. Strategies of rapid agricultural development need to be coordinated more directly with strategies for biodiversity and water conservation such as retaining areas of natural vegetation in production areas, keeping areas where pollinators can thrive, promoting organic agriculture and incorporating trees in agricultural landscapes.

The public good nature of many natural resources lends itself to consultative and collective approaches in the development of policies and institutions. Involving local communities in determining land use and land tenure policies and giving them control and responsibility over the resources increases the likelihood of efficient, equitable and sustainable use of common pool natural resources and compliance with rules and regulations. Examples include participatory forest

management, which is being introduced in a number of countries in sub-Saharan Africa. The collective, public goods aspect of on-farm agricultural biodiversity can be supported through international mechanisms such as Farmers' Rights provisions under the FAO International Treaty on Plant Genetic Resources for Food and Agriculture.

Farmers in sub-Saharan Africa often integrate trees on their farms and on landscapes in order to harness multiple benefits, including timber and other high value products, fuel wood, fibre, feed, medicinal products, fruits and ecosystem services, such as land rehabilitation and soil fertility through sequential fallow systems and systems with intercropped trees. Barriers to clonal forestry and agroforestry have been overcome by the development of robust vegetative propagation techniques, which are applicable to a wide range of tree species. Domestication, intensive selection and conventional breeding have had positive impacts on yield and the production of staple food crops, horticultural crops and timber trees. Agroforestry research builds on local knowledge and has the potential to reduce pressure on forests and provide ecosystem services such as biodiversity conservation, carbon sequestration and land restoration. Women and men have different priorities, which suggest scope for agricultural knowledge, science and technology to identify trees with multiple uses. Factors that need to be taken into account in agroforestry research include impact assessments, e.g., ensuring that trees do not jeopardize water supplies, especially in dry areas, and that exotic species are not introduced that cause social equity issues relating to land use and land rights. Other issues that need to be addressed include increasing adoption of agroforestry technologies, pests and diseases, markets for agroforestry products, availability of planting materials and adaptation to climate change.

Because livestock genetic diversity is being lost relatively rapidly, short-term strategies are required to provide information for priority setting. This might include as a first step, rapid surveys and population estimates and data on genetic distances. In the longer term, policies and market strategies to promote the use of indigenous breeds can provide economic incentives to conserve these breeds.

Community participation in livestock breeding increases the likelihood of appropriate traits being identified and developed. Yet information is still required with respect to how livestock owners make livestock selections and how livestock production fits with other livelihood activities.

Sub-Saharan Africa is the only region where per capita fish supplies are falling (from 9 kg per person in 1973 to 6.6 kg in 2005) as a result of stagnation in capture fish production and a growing population. Where capture fisheries are over-exploited, institutions need to be strengthened for allocating fishing rights, ensuring sustainable catches, and enforcing rules and regulations. Improved management of capture fisheries will also require strategies to reduce and use by-catch, and reduce postharvest losses. Working with local fishing communities and understanding their perspectives on externally enforced rules and regulations may reduce tensions between biological realities and community acceptance. Investment in supporting local fishers in modern fishing techniques could also go a long way in reducing tensions and improving livelihoods.

Unlike in other regions, aquaculture currently makes a very small contribution to total fish production in sub-Saharan Africa – just 2 percent compared with 38 percent worldwide. Aquaculture has the potential to improve livelihoods and nutrition, and reduce the pressure on capture fisheries. Agricultural knowledge, science and technology has a role to play in reducing the potential negative effects of aquaculture through learning from other regions, increased research into integrated farming systems that avoid using wild-caught fish as feed, and strengthening the capacity for impact monitoring, such as the impacts of chemical inputs and the conversion of mangroves to fisheries. Additional options for agricultural knowledge, science and technology include the need to develop post-harvest technologies, value chain and product development, farmer training and increasing access to inputs.

Agricultural intensification tends to be accompanied by decreasing agricultural biodiversity. However, farmers naturally play a role in conserving agricultural biodiversity that can be exploited and incorporated into more formal conservation

approaches. Genetic erosion is of particular concern in sub-Saharan Africa because many countries have a wide range of crops and livestock species that are considered relatively unimportant on a global level but are important as local staples. *In situ* conservation and protection is particularly important for conserving genetic resources, helping to maintain evolutionary processes and having a positive effect on biodiversity and equity.

Working with local communities has been shown to be key to conserving biodiversity and maintaining or enhancing ecosystem services in the long term. Market-oriented incentives enable local communities to benefit financially from sustainably managing soils, water, sequestering carbon and conserving biodiversity. These could include direct payments to farmers or to particular agricultural sectors; other types of rewards include well-defined property rights over natural resources in favour of local communities; the development of markets for indigenous species; and strengthening intellectual property rights.

Agriculture, health and nutrition in sub-Saharan Africa are closely linked. The emphasis of agricultural policies in sub-Saharan Africa on the production of a few staple food crops to the neglect of indigenous species with good nutritional properties, and micronutrient rich foods, such as fruits and vegetables, has reduced agriculture's potential to improve the livelihoods of households, including health and nutrition.

Increasing yields will have a direct impact on the nutritional status of the rural poor. General options to reduce malnutrition encompass increasing households' access to income and calories as well as encouraging a diet of diversified foods with the needed nutrients. There is scope for agricultural knowledge, science and technology to target micronutrient deficiency through increased research into the nutritional value of local and traditional foods, particularly fruits and vegetables, and the extent to which they contribute to diets. To ensure that the direction of agricultural knowledge, science and technology research is relevant to local communities and that its outputs will be widely adopted, additional research is

required into the conditions under which farmers will choose to cultivate and market these traditional food sources and households will choose to consume and purchase. The empowerment and increased involvement of women can help with the development, adoption and demand for more nutritious foods, such as orange-flesh sweet potato (*Ipomoea batatas*). Malnutrition is increasingly becoming an urban as well as rural problem. Options that are particularly relevant to the urban population include product development to increase the variety and quality of food, including fortified foods, and targeted information campaigns to increase awareness and encourage adoption of more nutritious foods.

Malnutrition and ill health in sub-Saharan Africa are exacerbated by tropical diseases, such as malaria and schistosomiasis, and by HIV/AIDS-associated diseases, such as tuberculosis, that result in a reduced workforce available to agriculture and other productive sectors. Animal-linked diseases affecting both human and animals have also been a significant setback to livelihood security, aggravated by unregulated cross-border movements resulting in the spread of transboundary diseases such as Contagious Bovine Pleuropneumonia (CBPP), African Swine Fever (ASF) and Rift Valley Fever (RVF). Agricultural knowledge, science and technology options to address these diseases include efficient vaccine development, rapid and accurate diagnostic techniques and breeding of animals with high tolerance to diseases. Policy options include control of animal movements across boundaries and this requires regional cooperation.

Most farmers in sub-Saharan Africa operate in an environment of high risk and uncertainty. Farmers therefore tend to adopt strategies that minimize risk and vulnerability at the expense of profit-maximizing strategies, resulting in an agricultural sector in sub-Saharan Africa that is well below its potential. Sub-Saharan Africa already experiences high variability in rainfall and other climatic extremes, which will be exacerbated by climate change. Resilience in much of sub-Saharan Africa is inhibited by fragile ecosystems, weak institutions, ineffective governance, and poverty; those most vulnerable are the poor who have the least

adaptive capacity. When agricultural knowledge, science and technology builds on farmers' and pastoralists' coping strategies and innovations thereby placing local people's knowledge and actions, such as diversified production practices used by 90 percent of sub-Saharan Africa farmers, at the centre of research efforts, the multiple functions of agriculture are better realized and the threats of climate change mitigated. Options include undertaking collaborative research with farmers, including the integration of crop, livestock, tree and fish components where applicable that spread risk and deliver various benefits at different periods throughout the year.

Few households in sub-Saharan Africa have private and transferable property rights to the land that they farm. Although secure land tenure correlates with long-term investments in natural resource management, land titling in itself has not been shown to increase credit transactions, improve production or increase the number of land sales. Any benefits are often offset by the high transactions costs of titling land and loss of rights of disadvantaged groups including women and pastoralists. However, land tenure reform in some cases may be necessary to secure individual or collective rights to resources in order to reduce farmers' vulnerability and strengthen women's access to resources. It is more likely to be effective and equitable if it is sensitive to the impact on the rights of disadvantaged groups and undertaken in parallel with the harmonization of other laws such as those governing inheritance. Collective action when resource and land tenure are secure has yielded benefits and reduced risks and costs for members through labour efficiencies, provision of public services and management of natural resources. The inclusion of a gender perspective in these institutions for collective action leads to more equitable outcomes.

Credit, insurance, and other risk-sharing institutions can reduce farmer exposure to risk and uncertainty and therefore enable them to increase expected output and profits. Microcredit is relatively well established in sub-Saharan Africa. Much is provided through NGOs and not all may be economically sustainable without the injection of external funds to cover the relatively high administrative costs. Recently retail banks are becoming involved in commercially viable microcredit by providing

capital to organizations that then provide the microcredit directly to farmers. An appropriate policy environment for easy access to affordable microcredit is most likely to benefit farmers. Alternatives to credit from the financial sector include the development of contracts that allow for advanced payment and provision of inputs and extension services from agribusiness companies to farmers, such as contract farming and outgrower schemes.

Weather insurance can reduce farmers' exposure to highly variable rainfall and hence crop yields provided they are in a position to pay for such services. Private provision of weather and crop insurance is only likely to occur for larger farms and high value crops. Some initiatives are being piloted by the World Bank that pay out depending on rainfall rather than crop output, thereby eliminating moral hazard (farmers may put less effort into their farming activities if they are insured against losses). Such insurance may be more relevant to drought rather than climate variability, but the problem of covariance remains (if one farmer is negatively affected the likelihood is that most farmers in the vicinity will be), suggesting that private companies on their own may not be willing to provide such insurance. Micro-insurance is already being introduced for small-scale farmers in a number of sub-Saharan Africa countries through partnerships between private companies, donor governments, and NGOs, but has not been rigorously evaluated.

Rangeland management approaches practiced by pastoral livestock farmers have been recognized as the appropriate response to knowledge of the spatial and temporal availability of resources. These strategies include movement of livestock to follow quality and quantity of feed and water, flexible stocking rates and herd diversification sustained by a system of communal resource tenure. Agricultural knowledge, science and technology needs to address emerging constraints and new realities for these pastoral systems brought about by land tenure changes, which conflict with traditional tenure, institutions, and carrying capacity in the context of emerging challenges such as climate change and associated stresses. These strategies are most likely to work if countries develop regional strategies to enhance the evolution of pastoral farming systems.

Options for agricultural knowledge, science and technology include the application of geographic information systems and quantitative modelling processes to provide further insights into productivity patterns of the system and offer policy options to ensure sustainability. Incentives and arrangements for local communities that designate rangelands for other uses such as biodiversity conservation have been attempted in some countries. The development of reliable early warning systems to avoid catastrophic effects of droughts and designing livestock management systems can help to alleviate the shortage of dry season grazing. Improving understanding and documentation of the role of livestock in livelihoods and motivations behind pastoralist practices will be most effective if conducted in pastoralists' languages using participatory methods.

The lack of connection between sub-Saharan Africa farmers and the market has seen agriculture remain rudimentary, unprofitable and unresponsive to market demand. Farmers' poor access to markets reduces incentives to apply agricultural knowledge, science and technology innovations and to make investments in modern technologies and so inhibits the shift of poor farmers from subsistence to market-oriented production. Weak markets result in expensive inputs and poorly developed output markets result in low farm-gate prices for internationally traded products. Weak business service sectors reinforce small producers' isolation from any but the most local markets and barriers to entering the formal market reinforce the inefficiencies and limitations inherent in the informal sector, with the result that the benefits of informality are outweighed by reduced competitiveness and increased vulnerability. Sub-Saharan Africa farmers have fared no better internationally. Between 1980 and 2000, most sub-Saharan Africa countries' agricultural exports to international markets stagnated at just 2 percent of the global market in spite of globalization trends that were expected to open new markets to sub-Saharan Africa products. It is critical that terms of trade between sub-Saharan Africa and international partners improve.

Options to improve the connection between farmers and the market include improving technical assistance in production and post-harvest techniques; training and capacity development and access to credit for long-term investments and product upgrading; investment in organizational and institutional development of farmer organizations to enhance farmers' management, negotiating, and bargaining skills; and promotion of agro-processing in small urban centres. Agricultural knowledge, science and technology has an important role to play in increasing production efficiency along the value chain by making modern technologies available and providing viable processes for transmitting marketing information and including information related to consumer preferences and price signals to farmers and agro-processors. Contract farming and outgrower schemes, which offer benefits related to guaranteed market access, access to credit and market information are being explored in the region.

The absence of processing and storage infrastructure located near the main producing areas inhibits value addition. Further, market development calls for infrastructure inputs, including rural road networks and electricity. There is a positive correlation between the development of transportation infrastructure and agricultural intensification; yet sub-Saharan Africa has the lowest density of paved roads of any world region. Information and communication technologies (ICTs) development is increasing access to and contribution of agricultural knowledge, science and technology knowledge in some parts of the region, but there is potential to achieve more impact.

Increasing the scope of marketing opportunities at the regional level, as stipulated in the Lagos Plan of Action and the Abuja Treaty, will increase trade and marketing opportunities. Further options include implementing existing regional agreements towards meeting targets; improving and harmonizing customs procedures and instituting policies for more efficient cross-border trade; and removing infrastructural and other barriers to the movement of commodities across borders.

Payments for environmental services (PES) are a market-based tool that has received substantial interest in sub-Saharan Africa. It creates incentives for

managing natural resources, directly rewarding management practices that contribute to maintaining and enhancing environmental services that result in biodiversity conservation, carbon sequestration, water quality and availability, and land rehabilitation and nutrient cycling. There has been some recent experience in sub-Saharan Africa where those that provide an environmental service are compensated for this by the beneficiaries of the service.

There is also increasing potential for African countries and small-scale farmers to be involved in voluntary markets for carbon and international market mechanisms such as the CDM (Clean Development Mechanism). Knowledge and strategies to reduce carbon emissions through community based afforestation and reforestation projects, agroforestry and reduced deforestation and degradation (REDD) are being generated, but need to be tested and adopted/adapted. These strategies have the potential to create synergies for increasing productivity and achieving the multiple functions of agriculture.

Other mechanisms such as certification, which may result in a premium paid to farmers, have to be carefully designed so that appropriate prices are set and the requirements for certified products are jointly negotiated. However, at present the costs of certification for small-scale farmers can be prohibitive. Agricultural knowledge, science and technology has a role to play in assessing and monitoring the impacts of these different, novel market approaches – decreasing transactions costs for local communities, and setting up appropriate policies and institutions that provide level playing fields for negotiation between buyers and sellers and determine whether the poor can benefit.

The dominance of external funding for agricultural knowledge, science and technology in sub-Saharan Africa has resulted in unreliable long-term funding and loss of control over the relevance and direction of new technology developments. Even with external funding, if Nigeria and South Africa are excluded, agricultural knowledge, science and technology spending in sub-Saharan Africa declined by 2.5 percent per year during the 1990s. A commitment by countries in sub-Saharan

Africa to reaching the Maputo Declaration's target of allocating 10 percent of the budget to agriculture has the potential in some cases to ensure more sustained and reliable public funding for agricultural knowledge, science and technology, increase its relevance for sub-Saharan Africa, and be a catalyst for increased coherence between donor and national policies. In parallel, better use can be made of current limited resources through existing regional and sub-regional networks enabling resource and expertise sharing; leveraging funding through cost-sharing with end users; the use of competitive grants, matching grants, trust funds, and specific surcharges such as levies and voluntary contributions. Furthermore, a strategic action at the national level on stimulating local private sector investment in food and agriculture and local agri-business could help.

Establishing funding mechanisms through performance-based competitive research funds and matching grants can enhance collaboration between various research partners. Public-private partnerships (PPP) offer a way to leverage public funding, but agricultural knowledge, science and technology research and development may be pulled towards commercial outputs at the expense of public good outputs and so still need to be evaluated against development and sustainability goals. Given the contribution of agriculture to improving human 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. More generally, shifting to a multifunctional localized approach to agriculture will require political will on the part of policy makers, agribusinesses and donors of publicly funded research to make more community-centred decisions about how to invest limited resources.

Current education, training and extension structures are incompatible with innovative approaches to agricultural knowledge, science and technology development. Most agricultural scientists in sub-Saharan Africa are trained and rewarded within a narrow discipline, reflecting the typically linear approaches to research and extension that value "formal" scientific research and learning over more tacit forms of farmer

learning and local and traditional knowledge. Proven approaches to research for development have evolved recently, with more attention paid to integrated solutions, spatial heterogeneity, tradeoffs, and livelihood and environment outcomes rather than only productivity issues. There has also been considerable emphasis in establishing coherence and synergies among basic applied and adaptive research as well as dissemination of results by encouraging collective participation of universities, private sector, public research organizations and civil society. New players, including some international NGOs, have joined in knowledge generation.

In sub-Saharan Africa, the generation of formal knowledge and scientific development rests predominantly with a research system comprising national and international agricultural research organizations, universities and the private sector. Often this research system is slow and inadequate in its response to challenges. This is partly due to poor access to current global literature and expertise. Typically it can also be attributed to education systems that inadequately prepare scientists to carry out effective research, and to poor linkages between education, research and extension. Education is still centred on learning facts rather than developing skills in problem solving and is constrained by disciplinary boundaries.

Options include improving the connections between education, research and extension systems, moving to problem-based learning, removing outdated disciplinary paradigms and updating the research approaches and tools being taught. Training can be expanded to include the socioeconomic and policy environment in which agricultural development occurs, and field-based research with farmers. A new cadre of specialists is needed who are able to offer technical support in appropriate tools and approaches. However, scientists are less likely to choose to undertake longer-term participatory and integrated research unless there are changes in the professional reward system that is currently based predominantly on the generation of data at meso and macro levels.

There is scope to explore the potential for efficiencies in regional graduate training models. The large number of small countries in Africa means it is often difficult for individual universities to achieve a critical mass of teachers in specialized

areas such as biotechnology. Appropriately designed regional training approaches may provide a solution. However, rather than creating new regional institutions, self-initiated efforts—building on regional specializations within existing universities and then developing networked training programs to attract students from a regional watershed—are likely to be more cost effective and have more impact, particularly in the short term.

New approaches to agricultural knowledge, science and technology generation that increase farmer involvement and include local and traditional knowledge naturally incorporate and enhance farmers' own technical skills and research capabilities. However, sub-Saharan Africa is the only region where formal education and government services function formally in languages different from the first languages of almost the entire citizenry. This linguistic divide, which reduces the scope for combining formal science and technology and local and traditional knowledge, can be addressed in part through the increased use and understanding of local languages when working with farmers.

Increasing the functional literacy and general education levels among rural communities, especially women, has already been proven to increase the likelihood of achieving development and sustainability goals. Additional options include specific curriculum reform that addresses the key skills required to empower individuals and communities to engage in the development and use of agricultural knowledge, science and technology, increase the likelihood of local and traditional knowledge being incorporated, and drive and contribute to agricultural product and service development. Specific actions to mainstream women's involvement include strategies that encourage women to study agricultural and engineering sciences and social sciences; and effort to ensure that extension, data collection and enumeration involve women both as providers as well as recipients. For example, 83 percent of extension officials in sub-Saharan Africa are men who, due to cultural norms cannot, or may choose not to speak to women.

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