Executive summary

The challenge of African agriculture

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

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

To answer these questions, United Nations Secretary-General Kofi Annan requested that the Inter-Academy Council (IAC) engage leading scientific, economic, and technological experts from around the world – but primarily from Africa – to identify how best to realize the promise and potential of African agriculture. This report is the result. Written by the IAC Panel on Agricultural Productivity in Africa, it details a number of concrete steps that the scientific community – working closely with farmers, governments and industry – can take to avert the risk of famine and relieve human suffering for millions of Africans in the years ahead.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Science and technology strategies

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

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

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

1. *Growth- and yield-defining factors (genetic potential, climate and weather)*: High-yielding varieties of many different crops are commonly grown throughout the world. These varieties have been the key to a dramatic increase in yield. In the past, for example, high-yield wheat and rice formed the heart of the Green Revolution in Asia. Given the diversity of production environments and farming systems in Africa, crop improvement research needs to use approaches that develop new varieties with a genetic potential specifically suited to local niches, placing a premium on participation and feedback from farmers.
2. *Growth- and yield-limiting factors (water availability, plant nutrition, soil fertility and labour)*: Crop growth and yield are limited by poor plant nutrition and uncertain water availability during the growing cycle. Depletion of soil fertility, in fact, is a major biophysical cause of the low per capita food production in Africa. This loss of nutrients can be counteracted by the application of appropriate fertilizers. Thus, research should be directed at understanding and resolving the factors that limit access to fertilizers, as well as those that can make fertilizer use more efficient. In addition, research is needed on the factors that can make irrigation more accessible and less costly for small farmers – and on techniques for improving integrated soil, water and nutrient management.
3. *Growth- and yield-reducing factors (weeds, pests, diseases and pollutants)*: Pests, diseases and weeds are a huge problem in nearly all farming systems around the world. Africa is no different. Cassava Mosaic Disease, for example, can completely destroy a crop in heavily infected areas. Whereas the possibilities for chemical control of pests and diseases are restricted because of limited availability and cost of pesticides, farmers find resistant varieties of plants to be a powerful tool whenever the appropriate varieties are available. Technology-driven options require the development of varieties with properties such as salt tolerance and resistance to the prevailing pests and diseases. Here, biological pest controls can offer a number of excellent alternatives to chemical control. Genes conferring resistance to pests and diseases have been transferred to certain target crops from a wide range of sources, far exceeding the biological constraints of conventional plant breeding. Although such biological pest control techniques reflect powerful alternatives to chemical pesticides and herbicides, these technologies have not yet been effectively applied to most African challenges.
4. *Post-harvest losses that reduce the distribution of foods to the marketplace:* Much of the food produced in Africa is lost in post-harvest processes. Some studies report staggering losses, ranging in some countries from 10 to 100 percent. Sweet potato, plantain, tomatoes, bananas and citrus fruit, for example, often perish before reaching the market. A reduction of this wastage would benefit growers and consumers alike. Local processing plants established throughout the African countryside could provide a critical solution to this problem. Local agro-processing not only restricts post-harvest losses; it also increases the economic value of harvested agricultural products. A policy oriented towards such development would produce much more innovation in food processing and distribution in Africa.

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

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

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

There are many documented examples of successful productivity-enhancing innovations. The challenges are both to scale them up and to develop new options for the future. For example, African agriculture should derive maximum benefit from both conventional plant breeding and biotechnology. Rapid developments in information and communication technologies – such as the Internet, the World Wide Web, and cellular telephones – also provide important new opportunities for improving agricultural productivity and food security in Africa. Information technology has also stimulated the development of comprehensive computation models, such as models of crop and animal growth. New mapping technologies provide important information for African farmers, scientists, and policy makers. Tools such as geographic information systems (GIS), global positioning system (GPS) and thematic maps of seasonal movements of livestock reinforce the identification of relevant know-how. Such mapping techniques, for example, can help to identify land boundaries, establishing the land ownership or tenure necessary for obtaining credit for agricultural investments.

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

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

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

Near-term impact

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

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

- *Pursue a strategy of integrated sustainable intensification*. The aim of science and technology should be to produce integrated soil, water, nutrient, and pest management approaches that are effective for African farmers. Knowledge-intensive and technology-driven approaches must be integrated with indigenous knowledge and farmers' needs and demands to ensure the appropriateness and adoption of these innovations.
- *Adopt a market-led productivity improvement strategy to strengthen the competitive ability of smallholder farmers*. Farmers should be able to respond effectively to price signals in the marketplace, aided by information and communications technology. This will help achieve a balance between supply and demand and provide incentives for farmers to close existing yield gaps, allowing them to become more income secure in the process.
- *Reduce land degradation and replenish soil fertility*. Soil health and fertility management holds the key to enhancing crop productivity in Africa. An integrated approach that includes exploiting the effects of both inorganic and organic fertilizers on soil, water and crop productivity can break the downward spiral of land degradation.
- *Recognize the potential of rainfed agriculture and accord it priority*. Because the possibilities for economically viable and environmentally benign irrigation development in Africa are limited, rainfed agriculture will remain the dominant system for decades to come. This type of farming, therefore, offers the best opportunities for the improved productivity that reduces poverty and food insecurity.
- *Explore higher-scale integrated catchment strategies for natural resource management*. The projected water scarcities in many regions of Africa require strategies and policies for its sustainable use to address the increasingly competitive multi-sectoral demands for water. These strategies should be explored to optimize land and water use to safeguard biodiversity, manage forest resources, and conserve native vegetation and wildlife habitat.
- *Enhance the use of mechanical power*. Encourage the local manufacture of agricultural machinery and equipment for all phases of agricultural production so as to enhance development and reduce the African countries' dependence for such goods on the industrialized countries of the world.
- *Embrace information and communication technology at all levels*. Vastly improved access to information and communications technology is essential to realize these opportunities and to reach the isolated and excluded villages of Africa.

Intermediate-term impact

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

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

Long-term impact

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

Institution building

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

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

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

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

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

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

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

The IAC Panel believes that Africa deserves a dramatic and sustained increase in the resources devoted to agricultural research and development. Higher salaries are needed for scientists. That said, however, good scientists value other aspects of their work in addition to competitive salaries. Social prestige and recognition, for example, and a working atmosphere in an institution that values merit and innovation are equally important. Above all, impact-oriented research organizations need visionary leaders to inspire and nurture their team to achieve great goals.

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

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

Near-term impact

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

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

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

Intermediate-term impact

- *Cultivate African centres of agricultural research excellence.* These centres (ACARE) should be designed to enable research on both continental and regional priorities as a complement to the national agricultural systems. By using modern communication technologies to network with other institutions with complementary skills and goals, each centre will become a virtual centre for particular research areas. Each would be African owned and governed, thereby providing a magnet for African scientists to remain at home, as they work to strengthen African national agricultural research systems. National academies of sciences in Africa and other nations (through the InterAcademy Panel on International Issues and the InterAcademy Council) should play a role in identifying suitable candidate research institutions that could become centres of agricultural research excellence.
- *Strengthen international agricultural research centres.* International agricultural research centres with headquarters and programs in Africa should retain their international identities. They should, however, operate in more collaborative and complementary modes with national agricultural research institutes and universities, and in participatory partnerships with both farmers and consumers. The level of investment in the CGIAR African centre programs for research and capacity building should be increased by 5 per cent per year, to at least US$235 million by 2015.

Producing new agricultural scientists

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

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

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

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

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

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

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

Near-term impact

- *Broaden and deepen political support for agricultural science*. Real improvement in agricultural education and research requires strong support from top political leaders. A coalition of supportive agricultural constituencies must be formed, including farmers associations, producer groups, national agribusiness companies, educators and researchers.
- *Mobilize increased and sustainable funding for higher education in science and technology, minimizing dependence on donor support*. There is an urgent need for an increase in both the numbers of students and the quality of their agricultural education (e.g., science, food processing, natural resource management, and rural development) at primary, secondary and tertiary levels. At the tertiary level, the 'sandwich model' provides an effective tool for building capacity while maintaining a focus on African needs. This model educational approach allows university students in developing nations to spend one year at a university in an advanced S&T nation, then return to their home universities for completion of their degree programs.

Intermediate-term impact

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

Long-term impact

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

rangle' recommended in this report). They should also become better sensitized to the socio-economic and policy environments in which agricultural development occurs and in which they will be working during their careers.
- Strengthen science education at primary and secondary school levels. A special emphasis must be placed on improving the accessibility and friendliness of science training to young women. Farm science schools where the pedagogic methodology is 'learning by doing' are urgently needed for the knowledge and skill empowerment of farmers.

Enhancing markets

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

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

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

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

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

Near-term impact

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

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

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

Intermediate-term impact

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

New science and technology pilot programs

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

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

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

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

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

1. Eradicate extreme poverty and hunger through a shift from unskilled to skilled work and through sustainable farming system intensification, diversification and value-addition.
2. Achieve universal primary education.
3. Promote gender equality and empower the technical training of women.
4. Improve maternal health and nutrition to avoid the birth of low-weight babies.
5. Combat HIV/AIDS, malaria, and other diseases.
6. Ensure conservation and the enhancement of basic life-support systems including land, water, forests, biodiversity and the atmosphere.

- *Science and technology pilot programs should be introduced where the following components of the production–processing–marketing–consumption chain can be developed in a participatory mode:*
  1. An assessment of indigenous technology options relevant to improvement of productivity and food security.
  2. An assessment of market potentials and constraints for existing and prospective commodities in the farming systems.
  3. An assessment of the scope for the following new technology options to enhance productivity and food security:
     - Integrated nutrient and soil fertility enhancement;
     - Integrated pest management;
     - Small-scale water harvesting and efficient and economic use through micro-irrigation systems of delivery of water and nutrients;
     - Biotechnological applications like improved genetic strains (including genetically modified organisms, where relevant), biofertilizers and biopesticides;
     - Use of improved farm implements and appropriate mechanization for increasing labour productivity, reducing drudgery and ensuring timely farm operations;
     - Introduction of appropriated post-harvest processing, storage and marketing techniques;
     - Promotion of non-farm employment through the introduction of technology options for adding economic value to primary products and through agri-business enterprises based on micro-credit;
     - An information and communication program to provide location-specific information relating to meteorological, management and marketing factors and to promote genetic, quality and trade literacy among smallholder rural farm families;
     - Establishment of farmer field schools for integrated pest, disease and weed management; integrated water and fertility management; and the other aspects of production and post-harvest technologies based on the principle of learning-by-doing;
     - Promotion of institutional structures like co-operatives and self-help groups that can confer the power of scale to smallholders at the production and post-harvest phases of farm operations.
- *For each pilot program, explore the scope for other institutional innovations such as:*
  1. Promotion of a participatory knowledge quadrangle coalition led by smallholders and involving them with universities, national agricultural research institutions and extension agencies to explore new modes of partnership.
  2. Identification of candidates for African centres of agricultural research excellence (ACARE) that would serve the interests of smallholders.
  3. Stimulation of public-private partnerships that

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

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

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

The promise and potential of African agriculture

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

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