# IAASTD SUB-SAHARAN AFRICA REPORT

## CHAPTER 3

## AKST: GENERATION, ACCESS, ADAPTATION, ADOPTION AND EFFECTIVENESS

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**Key Messages**

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

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

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

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

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

They are refined and expanded through NEPAD/FARA (New Partnership for Africa's Development/Forum for Agricultural Research in Africa) initiatives and programs.

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

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

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

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

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

11. **The safety and economic risks posed by genetically modified organisms (GMOs) are not yet well understood.** Countries have responded by developing biosafety policies and adhering to international agreements such as the Cartagena Protocol. Education on biosafety issues related to GMO testing is helping to address problems of risk assessment and management and strengthening regional policies and capacity.

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

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

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

## 3.1 Human Context

### *3.1.1 Human health and nutrition*

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

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

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

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

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

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

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

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

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

*Impact on agricultural extension services.* Agricultural extension workers play a pivotal role in adopting and transmitting AKST. As workers spend fewer hours on the job due to illness, extension services are curtailed. A local extension officer in Uganda noted that between 20 and 50% of total work time was lost as a result of HIV/AIDS. Staff members were frequently absent from work, attending funerals and caring for sick relatives (FAO, 1994). In eastern and southern Africa, HIV and AIDS have resulted in a high number of deaths of skilled workers, whose replacement will take time (Jayne et al., 2005).

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

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

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

### ***3.1.2 Gender dynamics in AKST***

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

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

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

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

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

Agricultural production and household management leave women "time poor." The use of improved farm implements and appropriate mechanization can increase productivity, reduce drudgery, conserve labor, and ensure timely farm operations while mitigating pressure on women.

However, adoption of strategies that primarily benefit women may be inhibited by men, who have greater decision-making power.

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

### *3.1.3 Education, training and extension*

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

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

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

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

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

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

In a bid to curb the loss of human resources, the Southern African Development Community (SADC) is developing a regional protocol to diminish competition from neighboring countries that attract professionals with higher salaries (The Herald, 2006). African leaders have responded through various initiatives, such as establishing regional model research institutions that provide specialized scientific training. Some have instituted policies to attract scientists back to their countries of origin. Other factors that are important for retaining professionals include increasing teaching incentives, enhancing school infrastructure and revising teaching methods to increase student performance.

## 3.2 Key Actors and Institutional Arrangements

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

### *3.2.1 Investment and economic returns*

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

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

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

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

### *3.2.2 National, regional and international actors*

#### 3.2.2.1 National actors and initiatives

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

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

Market-driven agriculture is placing new pressures on governments, communities and farmers to produce more for both domestic and international trade. National reforms remain vital for success, and the options for institutional reforms abound. Recently innovative national programs have supported agricultural organizations like those in Cote d'Ivoire (NASSP 2), Senegal (PSAOP) and Mali (PASAOP). They have strengthened relations between research and extension by promoting collaborative planning of research and development.

Cote d'Ivoire established Centre National de Recherche Agricole (CNRA), its national agricultural research center, in 1997, the first semi-private research institution. A key feature of the center is the autonomy of leadership from direct government influence, which facilitated implementation of reforms in the late 1990s. The National Agricultural Services Support Program (NASSP) was designed to provide appropriate agricultural services for farmers. NASSP 1 restructured the extension services, establishing a semi-private, demand-driven rural development agency, Agence Nationale du Développement Rural (ANADER). NASSP 2 created CNRA by merging two independent research centers, one working on forest humid zones and the other on savanna zones. CNRA decreased the number of staff members and offered higher salaries based on performance evaluation. Despite the recent political instability of Cote d'Ivoire, CNRA is an effective NARS implementing local and regional research using interdisciplinary methods in collaboration with international institutions. One of its more innovative features is a sustainable financing scheme from private investors. The financing objective is to provide 60% of capital assets and budgetary needs as the government contribution decreases to 20% of the total budget.

#### 3.2.2.2 Regional actors and initiatives

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

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

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

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

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

#### 3.2.2.3 International actors and initiatives

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

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

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

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

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

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

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

The Challenge Programs emphasize stronger North–South and South–South partnerships. The Challenge Program on Water for Food (CPWF) aims to increase water use in agriculture to improve livelihoods and to provide water for other users. The program is hosted by the International Water Management Institute (IWMI) and administrated by a consortium of 19 member organizations: six NARs, five IARCs, four ARIs, three international NGOs and a river basin agency (CGIAR Science Council, 2004).

## 3.3 Technology Generation and Infrastructure

### *3.3.1 Technology generation*

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

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

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

The distribution of technology is an integral part of any AKST system and can be accomplished via formal, informal or private distribution systems. The formal system typically involves the researcher or institution disseminating information to either a general public or specialized group through conferences, workshops and publications. This type of distribution is narrow in scope and the number of people affected is small. Knowledge is further distributed by extension services to its clients. Individuals in the community control access to information about specific topics and understanding these control mechanisms is necessary to increase the effectiveness of information dissemination (Sumbo, 2001).

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

#### 3.3.1.1 Local and traditional knowledge and innovation

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

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

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

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

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

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

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

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

#### 3.3.1.2 Biotechnology

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

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

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

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

Uganda established a biotechnology laboratory in Kampala in 2003 for tissue culture of such crops as the East African highland banana and coffee. Uganda is also conducting Bt cotton field trials this year (2007), while trials are imminent for a transgenic banana, developed in Belgium, with resistance to bacterial wilt and black Sigatoka fungal disease (Standard, 2007). The Program for Biosafety Systems is establishing country offices in both Kenya and Uganda to handle biosafety requirements in response to these developments.

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

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

### *3.3.2 Infrastructure*

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

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

#### 3.3.2.1 Transportation infrastructure

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

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

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

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

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

#### 3.3.2.2 Water and energy

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

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

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

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

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

#### 3.3.2.3 Storage and processing

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

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

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

3.3.2.4 Information and communication technology

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

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

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

*Insert Figure. 3-1. Level of competition in some ICT services in Africa in 2003. (Source: Int. Telecommunications Union, 2004)*

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

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

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

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

The SAT3, or SAT3/WASC/SAFE Consortium, an undersea fiber cable running from Portugal to South Africa and across the Indian Ocean to Asia, has component segments measuring a total of 28,800 kilometers (Fiber for Africa, 2007a). The system is divided into two subsystems, SAT3/WASC in the Atlantic Ocean and SAFE in the Indian Ocean. The consortium's 36 members (12 of whom are African countries) have invested US $600 million to build and operate for the next 25 years.

SAT3 has been controversial because its business model is such that members use it as a first-line business, making their profits from charging for communication access rather than using it to open up communication to facilitate the development and growth of second-line businesses. Moreover, there is no competing system. Thus, in consortium member countries, the incumbent telecoms operators have been granted a national monopoly and control the fees charged for international bandwidth. Consequently, prices remain high and there is little incentive to lower them.

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

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

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

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

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

## 3.4 Natural Resource Management and the Environment

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

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

### *3.4.1 Land and water management*

A number of strategies have been put forward to integrate the many aspects of agriculture in order to address sustainable livelihoods (Scoones, 1998). Among them are sustainable agriculture, integrated water and watershed management (FAO, 1997; Lal 1999), agroforestry

(Franzel et al., 2001; Beer et al., 2005), integrated soil fertility and nutrient management (Bationo et al., 1998; Vanlauwe and Giller, 2006) and local knowledge. Newer approaches such as ecoagriculture (McNeely and Scherr, 2003) build on the objective of conserving biodiversity while increasing productivity and livelihood security.

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

Assessments of the effectiveness of integrated natural resource management are mixed. One constraint is the lack of well-described pathways that can trace the effect of research outputs on development (Gottret and White, 2001). Hierarchical approaches contend with important questions such as who wins and who loses. Research in eastern Africa on integrated watershed management has shown that "participation" in diagnosing problems and implementing programs must move beyond community-level forums to socially disaggregated processes and explicit management of tradeoffs among diverse groups. Moreover, a mere set of activities and interventions will not revitalize a system unless its various components are explicitly analyzed for potential tradeoffs and synergies (German et al., 2007).

*Insert Figure 3.2. INRM approach.*

#### 3.4.1.1 Land and soil degradation

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

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

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

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

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

#### 3.4.1.2 Climate change

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

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

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

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

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

### 3.4.1.3 Agroforestry systems

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

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

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

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

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

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

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

#### 3.4.1.4 Tree domestication

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

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

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

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

Post World War II global concerns for timber supply drove the establishment of industrial plantations for sawn-wood and paper in Africa and elsewhere. Pan-tropically suitable timber species, such as *Pinus* spp., *Eucalyptus* spp., and *Acacia* spp. were preferred (Barnes and

Simons, 1994). These plantations were established predominantly on remote land or land of low suitability for agriculture, and they were primarily geared for export. In SSA, the most significant tree product required was fuelwood.

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

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

#### 3.4.1.5 Improved and adaptive crop cultivars

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

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

### 3.4.2 Water management

#### 3.4.2.1 Linking water, AKST and development and sustainability goals

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

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

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

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

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

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

#### 3.4.2.2 Protecting water resources and related ecosystems

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

Inappropriate land management in water catchments causes most soil erosion. Soil loss ranges from 1 to 56 tonnes $ha^{-1}$ $yr^{-1}$ (Okwach, 2000; Liniger and Critchley, 2007). Sub-basin soil loss varied from 12 to 281 tonnes $km^{-2}$ $yr^{-1}$ and suspended sediment discharge was as high as 200 kg $s^{-1}$ during peak flow soil and water conservation measures reduced soil loss. Soil loss for a conventionally plowed maize field with no mulch was 32 tonnes $ha^{-1}$, 10 tonnes $ha^{-1}$ with 50% mulch and 2 tonnes $ha^{-1}$ with 100% stover mulch from the previous season (Okwach, 2000). In northern Ghana and Burkina Faso the adoption of savanna and Saharan ecoagricultural practices reduced soil loss by 10 to 40% and increased groundwater recharge by 5 to 20%, depending on their effectiveness and adoption (Tabor, 2005). Appropriate AKST is available that can reduce degradation of water catchments, but its access, adaptation, adoption and effectiveness are limited in most places.

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

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

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

Improving the water supply in rainfed agriculture is required to unlock its potential. Maize yields of resource-poor farmers are generally less than 1 tonne $ha^{-1}$, whereas farmers who adopt modern technologies (improved seeds, fertilizers, etc.) obtain 1.5 to 2.5 tonnes $ha^{-1}$ (Rockstrom et al., 2007). This is partly because of high runoff and evaporation losses. Where AKST has been adopted, soil water is enhanced and crop performance improved. Mulching in a semiarid environment can increase maize by 35 to 70% (Liniger et al., 1998). In northern Ghana the improved access, adaptation and adoption of soil and water conservation techniques—stone bunding, mulching, water harvesting, composting and planting neem, acacia and mango trees—contributed to a maize yield increase from an average of 0.200 tonnes $ha^{-1}$ to 1.600 tonnes $ha^{-1}$ (Cofie, 2006). A combination of soil and water conservation practices, fertilizer micro-dosing and an informal inventory credit system that secures a fair price for produce and improves access to inputs has improved the livelihoods of over 12,000 farmers (Tabo et al., 2005). Yields of sorghum and millet increased 44 to 120% while farmer income increased 52 to 134%.

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

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

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

#### 3.4.2.4 Fair sharing and benefits from water use

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

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

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

### *3.4.3 Biodiversity*

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

#### 3.4.3.1 Agrobiodiversity

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

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

#### 3.4.3.2 Tree diversity

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

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

3.4.3.3 Livestock

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

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

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

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

### *3.4.4 Biosafety*

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

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

foods (ICSTD, 2005). For informed decision making, labeling will have to take into account language, literacy level and public awareness.

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

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

The SADC guidelines for GMOs have countries committing themselves to a harmonized approach in handling and moving GM food aid across boundaries (Balile, 2003). Countries with no national biosafety laws have been encouraged to use the African Model Law (AML) (Ekpere, 2002). Critics of the law state that it cannot be implemented in its present form as it would complicate countries' attempts to comply with the provisions of the Cartagena Protocol on

Biosafety (CPB) (Africabio, 2001). Specifically it was argued the AML is retrogressive in that it broadens the scope of products under review. Products that SSA states currently consider safe will need to be reevaluated. Implementing the law would not be compliant with stipulated timeframes for decision making under the CPB, nor would it be compliant with labeling requirements stipulated under CODEX, or with science-based decision making under WTO. With the GMO debate ongoing, public awareness education and participation remain paramount (Leshner, 2007) and will need to be pursued in a fully participatory manner.

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

#### 3.4.4.1 Regional biotechnology and biosafety initiatives

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

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

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

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

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

#### 3.4.4.2 Regulatory and legislative framework

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

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

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

## 3.5 Trade, Markets and Globalization

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

### *3.5.1 Local trade and markets*

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

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

### *3.5.2 Regional trade and markets*

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

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

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

The major regional trading areas in SSA are (1) the Economic and Monetary Union of West Africa (UEMOA), (2) the Economic and Monetary Community of Central Africa (CEMAC), (3) the Economic Community of West African States (ECOWAS), (4) the Southern African Development Community (SADC), and (5) the Common Market for Eastern and Southern Africa (COMESA). UEMOA and CEMAC are both preferential trade areas and monetary unions; the others are preferential trade areas only. The East African Community is a regional grouping that is increasing in significance; in 2007 it expanded its membership to include Rwanda and Burundi. The two countries bring an additional 15–20 million people to the EAC market, and they are a direct link to the Democratic Republic of Congo. Regional trade has increased more in some SSA trade organizations and bodies than in others: UEMOA, CEMAC and SADC have seen more trade increase than ECOWAS while COMESA has registered the least.

Regional trade agreements that combine both a preferential trade agreement and a currency union component are likely to be efficient in increasing intraregional trade (Carrere, 2004). It is for this reason that COMESA, established in 1983 as a preferential trade area, has ambitious plans for full economic integration, including the free movement of people by 2014 and currency union by 2025 (Carmignani, 2006; Gupta and Yang, 2006).

The potential for regional trade is huge. Intraregional trade development in agriculture, formalizing existing informal trade, value addition and ICT are all largely unexploited trade opportunities. Sub-Saharan African countries currently import food products equivalent to 14% of global imports (Yeats, 1998), though they have a comparative advantage in producing and exporting these commodities. Additional benefits are also likely to accrue from formalized existing informal trade in food and food products between countries that share common borders.

The trade potential from processing and value addition and in services from medical to education to ICT is enormous. African economies that produce commodities could benefit from moving up the value chain and process foods they produce rather than export raw materials. For example, Ghana, the world's second largest cocoa grower, has moved slowly into making chocolate; Ethiopia, which has been growing coffee for a thousand years, still exports raw, unprocessed beans. Rwanda, which has moved into specialty coffee, exports less than 10% of its coffee fully washed. This is despite the fact that these countries face no EU tariff on chocolate and on roasted and ground coffee. A major limitation to processing and value addition in SSA may be attributable to the lack of a business climate conducive to investment and good transportation infrastructure. These obstacles will likely require regional solutions, especially for smaller economies, which would benefit from the promotion of regional trade. It will be difficult for sub-Saharan Africa to participate more profitably in global trade without establishing a regional presence and national and regional infrastructure for value addition for local producers.

Factors that affect regional trade groupings and make them less competitive in SSA include lack of needed infrastructure, unfavorable geography and low GDP. Another factor that affects the competency of regional trade arrangements in SSA is the number of overlapping initiatives, such as in eastern and southern Africa.

In SSA regional trade arrangements have (1) created incentives for removing restrictive trade practices and licensing procedures, (2) streamlined customs procedures and regulations, (3) integrated financial markets, (4) simplified transfers and payment procedures, and (5) harmonized taxation. Countries have gone even further, seeking to harmonize investment incentives, standards and technical regulations, as well as policies relating to transportation, infrastructure, labor and immigration.

Regional economic integration may help prevent SSA from becoming more marginalized as a result of globalization and competition with trade and economic blocs in other parts of the world. Regional economic integration can improve the success with which SSA articulates its concerns and prevent international agreements that may disadvantage SSA. An assessment of the effect of economic communities on trade and growth in SSA shows that regional agreements are far from reaching their intended goal of integration (UNECA, 2005). Achieving the highest level of integration are SACU, UEMOA and EAC. The most successful regional integration has been where a relatively compact geographical neighborhood coincides with other essential elements such as colonial past, language and macroeconomic parameters like currency and customs union.

Empowerment of regional economic corporations can improve the negotiating power of SSA and help meet the international sanitary and phytosanitary standards that will allow for more participation in international trade. Scientific and technological advances can also be shared through regional economic cooperation.

### ***3.5.3 Global trade policy, market infrastructure and links and market barriers***

Globalization is a major driver shaping the evolution of markets for agricultural goods, and thus the evolution of AKST and the adoption of agricultural technologies.

#### 3.5.3.1 Trade policy and global market dynamics

International trade and prices influence growth in SSA, because most SSA economies export raw agricultural commodities. Agriculture accounts for about 40% of exports (Townsend, 1999). The trends of world prices and especially of primary crops have been fluctuating. This historical downward trend negatively affected the growth of SSA economies.

There is no doubt that trade is an effective source of growth for SSA. However, it requires improved efficiency in the trading sectors. Distortions in WTO regulations and the SSA position as a supplier of raw materials have contributed to the low levels of economic growth. SSA farmers will face reduced competition if subsidies on exports from European and other developed countries are removed. Similarly, removing the taxes that most African governments impose on food production and consumption could stimulate farm investment and lower food prices (IAC, 2004). The US decision in May 2002 to increase its domestic agricultural subsidies by 67% will not enable SSA to increase agricultural exports.

SSA countries tend to enjoy little leverage within the global economy. One view is that leverage can best be strengthened through regional cooperation. This is to be in parallel with globalization within the scope of WTO. The aftermath of decisions made in previous WTO meetings has disappointed African countries. Benefits of African, Caribbean and Pacific–European Union (ACP-EU) negotiations have been negligible. Although world market prices for some commodities have risen recenty in general during the last two decades, the adoption of internal and international market liberalization polices and other associated agricultural sector policies promoted by international financial institutions has led to a catastrophic fall in the prices of many of the agricultural products exported, especially by East and Central African (ECA) countries due to systemic overproduction stimulated by components of structural adjustment programs. The major flaw in this strategy was that similar advice was given to almost all tropical countries at the same time; for example, coffee-producing countries were encouraged to boost coffee production and sugar producers to produce more sugar; crops in which these countries had a comparative advantage. This resulted in overproduction of these commodities, which caused prices to plunge in the international markets and less income to be earned as more commodities were produced.

ECA countries are highly dependent on the production of cash-crop commodities for employment, economic growth and export revenue. Countries that produce and export raw commodities such as coffee, sugar, tea and cotton through small-scale production systems are unable to create new jobs or reinvest in alternative market sectors. Thus countries and individual farmers who rely on cash-crop production for revenue are obliged to continue to grow and sell these commodities, no matter how low prices fall (Robbins and Ferris, 2003).

While the neo-liberal principles of structural adjustment programs led to trade liberalization in many countries with exchange rate adjustments, a decrease in trade tariffs and abolishment of parastatal marketing boards left African producers facing inequities in international trade with mainly the EU, the United States and Japan, which continued to protect their markets against imports from developing countries. The support and trade protection measures of industrialized countries reduced net agricultural exports of developing countries by nearly US $40 billion, resulting in an annual loss to agriculture and agroindustries in developing countries overall of US $24 billion (Orden et al., 2004). It is estimated that if industrialized country trade barriers were abandoned the value of SSA exports might increase by one-third, adding US $2 million to agricultural GDP (IFPRI, 2004).

Trade has significant potential to benefit the poor but only if enabling policies and institutional infrastructures are in place. Advocates of market liberalization, however, concede that the notable exceptions to this rule are African countries where growth is not evident. Globalization has further exposed and intensified existing structural and institutional weaknesses in some SSA countries. The expanding global market requires consistent economic policy formulation and implementation and transparency in governance.

#### 3.5.3.2 Market infrastructure, links and barriers

Robust market infrastructure is important, and will underpin Africa's ability to benefit from new trade opportunities. New export opportunities are emerging for nontraditional export crops, livestock production and processed foods, but mostly for producers who are well connected to markets and who can meet quality standards. To capitalize on this potential requires regional, national and local markets to be linked more explicitly than they are currently (Diao et al., 2005).

The following elements comprise a strategy to stimulate broad-based growth in agribusiness by developing micro- and small-enterprise agricultural production and marketing (Steen et al., 2005):

- A policy and regulatory environment that provides incentives for small-scale producers and micro- and small-enterprise (MSE) participation in markets.
- Vertical links—and systems of vertical coordination—that take a long-term, inclusive approach to working with small-scale producers and MSEs.
- Horizontal links and cooperation among like firms to reduce transaction costs and achieve external economies.
- Upgrading of both the chain and firms in the chain by promoting product and process innovations, improving the flow of information and learning, and addressing systemic constraints.
- Support of markets to ensure sustainable access to finance, business services and inputs.
- Competitive strategies that bring these elements together into commercial solutions that offer developmental benefits, i.e., national branding, penetration of niche markets and social marketing strategies.

Globalization and the increased competition that accompanies it requires African agricultural producers to build their capacity to comply with exacting standards of food quality and safety, as well as production (e.g., in markets for organic produce) and differentiate their products from those of their competitors to compete favorably in industrialized country markets.

This requires an AKST system and a market infrastructure that meets producers' needs for information about these standards and information about market demand and quality. Stronger institutions are needed for technical assistance—producer organizations and regulatory bodies, and also private sector entities such as exporters that provide technical assistance commercially or as an embedded service. These organizations can speed market development by helping develop processing systems that enable producers to conform to established standards and quality control and that facilitate quality certification. Legal and regulatory environments are needed that ensures contracts are enforced and that there are efficient channels for market information and product promotion. Also needed are ancillary business services such as credit and other financial services, risk mitigation in the form of crop or rain insurance, transportation and storage services, accounting and business training services, and price information services, as well as policy-maker commitment to market reform and effective marketing institutions. Key to the AKST system is an information infrastructure that can convey information related to both production and marketing of agricultural products, in all appropriate languages and media.

On the production side, information needs include everything from meteorological information specific to distinct agroecological zones, knowledge about crop varieties and management, soil and water conservation, animal husbandry, and agricultural technologies and inputs, to information about credit availability (including supplier credit for fertilizer or feed, etc.), postharvest techniques, processing and value-adding techniques, and other extension assistance.

On the marketing side, information needs range from trade literacy and knowledge of market demand for current commodities and potential opportunities for prospective commodities to processing standards and means of compliance, price information, and so on. The infrastructure for marketing agricultural products includes institutions through which information can flow and which facilitate trade in agricultural commodities. These institutions include ministries of agriculture, producer organizations and cooperatives, bureaus of standards, and private sector providers of business services offering technical assistance in quality control and standards as well as market links. In Africa, these institutions are often weak and under-funded.

Strong market infrastructures include formal and contractual as well as informal links among participants all along the various value chains through which agricultural products are financed, created, processed, traded and consumed. Producer organizations are also an important part of the market infrastructure, given the small scale on which many agricultural products are produced and their consequent disadvantage in the marketplace in the absence of a means of pooling products and consolidating the marketing of those products.

*Financial services*. Microfinance is an essential aspect of sub-Saharan Africa’s agricultural market infrastructure. Much of Africa’s agricultural output is generated by small-scale producers and other microentrepreneurs. Microfinance—financial services whose scale matches the needs of micro- and small-scale producers—is therefore the way agricultural producers are able to expand their production, buy fertilizer and other inputs, adopt new technologies, and smooth seasonal fluctuations in household expenses and enterprise income. Microfinance introduces flexibility into small-scale and microproducer investments and asset building. Newer financial services and products, such as crop or rain insurance, are also critical to reduce the risk associated with adopting new technology, innovating production and marketing methods. Credit terms tailored to agricultural production and marketing, such as loan repayment terms that track seasonal crop production, are critically important to enable agricultural producers to take advantage of economic opportunities.

Agricultural microfinance includes not only the products and services financial institutions offer, but also credit and other value-chain services. Those in the value-chain respond to different drivers of credit supply and demand than do financial institutions. They can accept more risk, and they have more information about the risks and likely benefits associated with particular agricultural endeavors. They also extend credit differently, e.g., through advance purchases, grace periods for payments for inputs, and embedded services that carry no direct costs.

Supply and demand of rural and agricultural credit is constrained by several factors (Chalmers et al., 2005):

- Distance from the financial institution's branch, low population density and sometimes difficult terrain increase the effort involved in reaching clients and push up transaction costs, which in turn decrease the financial institution's margin and incentive to reach rural and agricultural clients; when transaction costs are transferred to clients, they suppress demand because of the high cost of borrowed funds.
- Fluctuations in income for producers increases the risks associated with credit. Borrowers are less certain about their ability to repay than they would be if their income were more consistent, and lenders are less certain that they will be repaid in accordance with loan terms. Moreover, traditional and most prevalent credit products are not tailored to agricultural production cycles, so repayment often begins before harvest or during a low season, which can increase the risk that producers will default—a negative outcome for both borrowers and lenders.
- Agricultural production can be risky due to variability in climate and weather conditions, quality of seed or stock, availability of seasonal labor, etc. Marketing agricultural produce is likewise subject to exogenous factors. Because repayment depends on yield and ability to dispose of yield at a profit, these uncertainty factors translate into high risk for both borrower and lender.

- Information about borrowers' creditworthiness is not reliably available in most developing countries, particularly in rural areas. This lack of information increases financial institutions' risk when they lend to clients in these areas.
- If collateral is required to obtain credit, many micro- and small-scale agricultural producers have little or no hope of meeting the collateral requirements.
- Inhospitable policy, legal and regulatory frameworks often prevail in rural and agricultural areas of sub-Saharan Africa. For example, land titling may be nonexistent, or it may lend itself to bias, such as when women are responsible for cultivating land to which they are not legally entitled to hold title.
- Low availability of savings services also inhibits agricultural production; lack of rural deposit services, or mistrust of them among would-be savings clients, prevents agricultural producers from saving the capital needed to build their assets and increase their productivity (Charitonenko et al., 2005).
- Where they are available, rural equipment-leasing schemes (Rozner, 2006) and other suppliers of credit, as well as remittance services, can address this market failure in formal rural credit, which in turn can aid farmers to adopt new technologies. In addition to credit, crop, weather and geographic-based insurance, which are emerging products in SSA microfinance, can help create safety nets for small-scale producers.

*Nonfinancial and business services value-chain links.* Business service providers in some parts of SSA offer technological solutions that enhance agricultural producers' competitiveness by reducing unit costs of production, improving product quality and adding value at various stages, including on-farm production, postharvest storage and treatment, agroprocessing, marketing and transport. Postharvest losses in Africa are high; substantial improvement in profitability could be gained by improving roads and markets, as well as encouraging private sector investment in research and development at the lower end of the production-to-market chain (Rozner, 2006).

Competitiveness in global markets is generally enhanced when agricultural commodity markets are segmented and product quality, branding, and marketing are tailored to that market segment. Coffee is one example. By changing their processing methods and extending technical assistance to their members, coffee cooperatives in Rwanda are able to sort and process beans in accordance with quality standards set by European and North American markets. They establish market links with roasters who will guarantee a premium price in return for quality-controlled, stable coffee supplies. In some cases, producers have realized additional value through national branding (e.g., Ethiopian Yirgacheffe, Kenya AA). This is an example of how farmers can benefit by applying agricultural knowledge of how to control commodity quality through production and processing to enhance competitiveness and returns in the market for that commodity.

#### 3.5.3.3 International standards for agricultural production

The global rise of supermarkets is an important driver of change in agricultural production. Foreign direct investment in supermarkets and breakthroughs in retail procurement logistics, technology and inventory management have changed the way that agricultural products are marketed in many developing countries. The impact is currently felt mostly in relation to international trade, although there are some implications for local and regional trade. While few countries in sub-Saharan Africa (except for South Africa) host thriving supermarket chains at this time, this trend is likely to spread throughout the region over the coming decades as knowledge transfer makes the cost savings realized elsewhere possible in sub-Saharan Africa, and in response to increasing urbanization. Currently, the far more significant effect of this trend is on producers in the region who are selling into supermarket chains in global markets. With such a diverse supply base, retailers find it increasingly critical that minimum standards be in place to protect consumers and ensure quality. Consequently, developing-country producers of all sizes must ensure a steady supply of commodities that conform to international quality standards covering everything from variety, color, size and maturity, to odor, cleanliness, packing, mechanical damage and temperature maintenance. International food safety and quality standards can function both to facilitate producers' entry into regional and global markets and to exclude them from those markets, depending on a range of conditions.

A number of public and private food safety and quality standards regulate not only food safety but also environmental impact, occupational health, worker safety and welfare, and animal welfare. Hazard Analysis and Critical Control Point (HACCP) is a collection of food safety standards promulgated internationally by the Codex Alimentarius Commission (FAO/WHO, 1999) and aimed at reducing health risks in production. Other international standards govern classification categories such as organics and fair trade products. Organic and fair trade certification has proved invaluable for producers seeking, and able, to occupy niche markets, for example in origin-branded coffee (e.g., Ethiopian Yirgacheffe and Kenya AA).

For many sub-Saharan African producers, for whom European markets represent the most accessible export opportunity, EurepGAP (Euro-Retailer Produce Good Agricultural Practices) is the relevant set of sector-specific standards for farm certification for producers wishing to sell fruits and vegetables, flowers and ornamentals, livestock, aquacultural commodities and green coffee into European community markets. EurepGAP's stated aim is to ensure integrity, transparency and harmonization of global agricultural standards of food safety (including maximum residue levels from pesticides), traceability, worker health, safety and welfare, environmental preservation and animal welfare. Certification requirements have spawned private sector certification bodies (EurepGAP maintains its neutrality by empowering other bodies to conduct the actual certification). Currently, EurepGAP is working with over 100 certification bodies in more than 70 countries. It also recognizes other international standard regimes to reduce the burden on agricultural producers of multiple audits (EurepGAP, 2007).

The impact of such standards on the horticulture industry in sub-Saharan Africa is complex. In some countries, increasing adoption of practices required to meet these requirements has resulted in spillover into domestic markets of technology, quality assurance and management of supply chains. Proponents argue that by applying the recommended protocols on good agricultural practice, small-scale farmers not only enjoy a premium market outlet but experience increased income through gains in productivity and yields as well. In Zambia, for example, farmers have embraced EurepGAP standards as good business in terms of tracking inputs (which reduces theft), improving farm management (which results in higher yields), and increasing group bargaining power (which brings better prices). Improvements in worker safety and food safety vis-à-vis pesticides are also reported (Graffham, 2006). In this sense, the requirements producers must meet to enter the market have generated new agricultural technologies and practices, as well as more favorable market conditions for certain products.

Despite the spinoff benefits of the market-driven requirements and technologies, these increasingly rigid standards may have negative effects as well, serving as a form of import protection for domestic industry, particularly when restrictive measures raise the cost of imported produce. Proposed controls on carbon footprints can compromise the competitiveness of African products in European markets, or exclude them from those markets altogether. Moreover, smaller producers sometimes find certification requirements prohibitively costly and are unable to comply because they lack the resources and expertise to maintain the requisite quality management system. They are also sometimes unable to afford the certification charges (including the fees charged by local certification bodies—in Zambia, for example, fees have been as high as those charged by international certifiers). In fact, at present, the costs associated with training, infrastructural development, testing and analysis, pre-audit inspections, and certification are largely funded by donors. It is unlikely that the private sector will assume these costs in the near term. Some international development agencies (funded by multilateral and bilateral donors) now work with producer associations to help integrate food safety standards into their projects, not only to prepare producers to enter global markets but also to ensure that those not yet ready will adjust their practices in such a way as to avoid exclusion later when they prepare for export (Hobart, 2004). Producers without access to such assistance, however, may find their margins are insufficient to cover the costs of certification and maintenance. In this way, certification requirements to enter export markets may further segment small-scale producers, with new opportunities for the wealthier and reduced competitiveness for the poor.

For countries such as Kenya, however, EurepGAP cannot be ignored, as the EU represents up to 80% of Kenya's market share in horticultural commodities. Comprehensive data on the impact of standards regimes on African agricultural producers are lacking.

*Subsidies and dumping.* While globalization of markets has the potential to open up new export markets for African agricultural products, this potential is conditioned by policies implemented in industrialized-country markets, including agricultural and export subsidies and dumping, and market barriers. Subsidies and dumping of agricultural commodities produced with or without subsidies close off many options for national and regional sales of SSA agricultural commodities; often even displacing those commodities from domestic markets by introducing unfair competition from cheap, subsidized goods.

Dumping of imported agricultural commodities, poor road and transportation networks and weak market links suppress incentives for SSA producers to expand, adopt new technologies and transform processing operations to comply with export-market standards. In the absence of equitable terms within which they can compete. Thus in the absence of a market infrastructure through which they can sell their products, African agricultural producers frequently view the risks of adopting new technologies, investing in the production of new goods or increasing production of traditional goods, as too high. These risks are increased as markets liberalize and price volatility ensues. Suppression inhibits production for export and for domestic consumption (since increased production without export opportunities and good markets results in price drops), which in turn impedes efforts to achieve food security for Africa. This competition from subsidized and dumped goods also hobbles African agricultural producers vis-à-vis unsubsidized competition for Africa's traditional export markets from Latin American and Asian producers, in the sense that it renders them less able to compete effectively even in these market relationships (IAC, 2004).