SSA CHAPTER 2

TYPOLOGY AND EVOLUTION OF PRODUCTION, DISTRIBUTION AND CONSUMPTION SYSTEMS

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Key messages

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

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

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

4. **Animal and crop productivity and production increases in SSA are due, in part, to the utilization of genetically improved materials which are well adapted to harsh conditions and tolerant to pests and diseases.** Indigenous animal breeds of SSA are preferred due to their low management costs, as they can withstand harsh conditions and are tolerant to most diseases. However, their performance in terms of meat, milk and egg production has been low due to limited genetic potential and poor management. Advances in AKST have helped to improve the production potential of these animals, through record-keeping and individual identification for appropriate breeding purposes. Community-based characterization, conservation in gene banks and utilization of indigenous animal genetic resources through open nucleus breeding schemes, for example, are important. Community participation is essential for the

extension and propagation of new breeds. Cowpea and sorghum grain yield increases of 61.4%, and 46 – 50%, respectively, have been achieved since the first half of the 20th Century. The SSA region has an enormous agricultural potential in its crop genetic resources through many centuries of adaptation to the environment. Conservation, characterization and utilization of this germplasm through conventional breeding as well as through new technologies are keys to providing more and higher yielding varieties. Other factors that have contributed to the increase in productivity include the use of improved good quality seeds, timely and adequate application of fertilizers, application of appropriate pest control measures and good market prices.

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

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

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

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

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

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

2.1 Crop Production

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

2.1.1 Land, soil and water management

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

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

2.1.1.1 Land management

Sub-Saharan Africa has over 23 million km2 of land with a potential arable area estimated at 643 million ha and forest at 700 million ha, which is being cleared at the rate of 3.7 million ha per year (World Bank, 1989). Only 174 million ha of the land are currently under cultivation. However, in some countries such as in Burundi, over 93% of the population is rural and entirely reliant on agriculture for their survival and income, hence most of the land, 90% of the total cultivated area, is devoted to food crops and 10% to export crops (Leisz, 1998). Land lies at the heart of social, economic and political life in most of SSA, but across many countries there is a lack of clarity regarding land tenure. National policies on land tenure systems are contested throughout the region.

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

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

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

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

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

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

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

2.1.1.2 Soil management

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

2002, four countries account for 62.5% of all SSA fertilizer consumption: South Africa (38.8%); Nigeria (8.7%); Zimbabwe (7.6%); and Ethiopia (7.4%) (Ukeje, 2004; Kelly 2006). Mineral fertilizer consumption in Niger is the lowest in the world and amounts to only 0.3 kg of plant nutrients per hectare on average (World Bank, 1997). Limited financial means and the lack of subsidies seem to be the primary reason of the absence or low application of fertilizers and chemicals.

To date, fertilizer use in SSA has not led to increases in agricultural productivity on the scale observed elsewhere. Fertilizer consumption is only 9 kg ha^{-1} within the region compared with 73 kg ha^{-1} in Latin America, 100 kg ha^{-1}in South Asia, and 135 kg ha^{-1} in East and Southeast Asia (FAO, 2004a). Such low levels of fertilizer use, combined with shorter fallow periods and insignificant organic fertilizer inputs represent a serious threat to agricultural sustainability. African soils are being steadily depleted of nutrients due to farming without fertilizers (Matlon, 1987; Stoorvogel and Smaling, 1990; Van der Pol, 1992; Cleaver and Schreiber, 1994; Sanders et al., 1996; Steiner 1996; FAO, 1996; Buresh et al., 1997; Sanchez et al., 1997; Smaling et al., 1997; Bationo et al., 1998; Eswaran et al., 2001). There are two perceptions about the future of fertilizer use in SSA. One is that SSA needs to increase fertilizer use from 9 to at least 30 kg ha^{-1} during the next decade. The other is that the increased use will have undesirable environmental impacts such as soil acidification, water pollution and health problems. No single approach is sufficient to improve soil fertility in SSA. Integrated soil management, combining organic fertilizers (compost, manure, green manure) and reasonable quantities of synthetic fertilizers is an approach adaptable to locally available resources. Recent research on marginal soils in Burkina Faso by ICRISAT has shown that it is possible to increase millet and sorghum yields profitably by using inorganic fertilizer in combination with techniques that conserve and concentrate soil moisture and organic matter (http://www.icrisat.org/gt-aes/IFADPamph.pdf).

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

In some SSA countries, programs were imposed during the colonial and post-colonial eras to solve wind and runoff erosion and water problems. This is the case in the region of Machakos in Kenya, where a program of terrace-building was imposed during the fifties and led to the yearly building of about 5000 km of new terraces (Tiffen et al., 1994; Mortimore and Tiffen, 1995). In Zimbabwe, colonial authorities had imposed the building of more than 7000 km of small breakwaters between 1929- 1938. This practice continued until 1957, totaling more than 200,000 ha of communal lands (Whitlow, 1988).

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

International Institute of Tropical Agriculture (IITA), International Livestock Research Institute (ILRI), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Centre for Research in Agroforestry (ICRAF), and other research centres, governments, universities and NGOs have been working with farmers and national scientists to identify appropriate solutions to increase productivity in sustainable ways. A number of promising technologies, such as natural resource management (NRM), integrated soil fertility management (ISFM), improved land husbandry (ILH), soil and water conservation (SWC) and conservation agriculture, have been developed and adopted with some success. For example, mucuna (*Mucuna pruriens* - velvetbean) cover cropping is an example of the introduction of a simple regenerative component into farm systems which increases the farmers' capacity for local-adaptation of the technology. It contributes to alleviate the constraint of low supplies of maize, the staple crop.

Soil and water conservation in the drylands of Burkina Faso, Mali and Niger has brought remarkable transformations of formerly degraded and abandoned lands with the adoption of tassas (in Niger) and zaï (in Burkina Faso), traditional water-harvesting techniques. The average family in Burkina Faso using the zaï technology has shifted from being in annual cereal deficit amounting to 644 kg (equivalent to 6.5 months of food shortage) to producing a surplus of 153 kg per year (Reij, 1996).

2.1.1.3 Water management

Water scarcity is becoming one of the major limiting factors to economic development and welfare in large parts of sub-Saharan Africa. Unfavourable climatic factors such as erratic rainfall, high evaporative demand, several drought series, etc., contribute to water scarcity. In areas where the climate is hot and dry (e.g. the Sahel region), irrigated lands are subject to substantial water losses through evapotranspiration. Salts contained in precipitation and irrigation water remain in the soil and increase in concentration when the water evaporates from the soil or when the plants take up water for transpiration. If the salt is not leached from the soil, the salt concentration increases constantly, subsequently causing reductions in crop yield. Sub-Saharan Africa lags far behind the rest of the world in proportion of irrigated arable land and its contribution to total food production. In terms of value, irrigation is responsible for an estimated 9% of the crops produced in SSA (Yudelman, 1994). Irrigation development in SSA was initiated during the colonial period with the construction of irrigation schemes by private companies from Europe in the major river basins and also in the inland valleys for the production of tropical fruits and vegetables for European markets. After independence, public sector irrigation schemes have been accompanied by a growing number of new initiatives by private sectors. The management of the irrigation systems is generally ensured jointly by the State, as regards the primary infrastructure or public systems, and by users associations for the secondary and tertiary infrastructure, or by private systems. The disengagement of the State from the irrigation sector since the 1980s, and the subsequent creation of user associations (in place or planned in South Africa, Burundi, Côte d'Ivoire, Ghana, Madagascar, Mali, Mauritius, Niger, Nigeria, Senegal, Swaziland, and Zimbabwe), as well as the more recent promotion of participatory approaches (Burkina Faso, Mauritania and Chad) concerns about 20 African countries. The example of Kenya illustrates the choice of management transfer; all new irrigation schemes created between 1992 and 2003 are private, while some former public schemes are still partially administered by the state.

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

Yet water management is less advanced in sub-Saharan Africa than in any other developing region. The percentage of arable land that is irrigated is about 4.0% compared to 37% in Asia and 15% in Latin America. This figure that rises to 7% in Africa as a whole given that 40% of the total irrigated area is in North Africa (NEPAD, 2003). The irrigated area in SSA is concentrated in South Africa (1.5 million ha), Madagascar (1.1 million ha). Nine other countries (Nigeria, Ethiopia, Mali, Somalia, Tanzania, Zimbabwe, Senegal, Zambia and Kenya) each have more than 100,000 irrigated hectares. About half of the irrigated areas are small-scale systems. Equatorial Guinea has no irrigation because of the climate conditions. In 2002, Madagascar had 1,086,291 ha of irrigated areas representing 30.6% of total cultivated areas. Water is collected mainly from dams, or diversions from rivers or channels and dispatched by gravity. In 2000, irrigated rice with total or partial water control had grown to over 1,062,398 ha, representing about 75.8% of total rice areas. Other irrigated cultures are cotton (0.11%) and sugar cane (0.22%). About one third (28.2%) of the irrigated rice areas are traditionally managed i.e., by family groups, without government intervention. They are scattered in the inland valleys and each perimeter rarely extends over 10 ha (FAO, 2005a). This irrigation system is similar to Asian farming practices. Irrigation water is essential for puddling the rice field while drainage is needed for avoiding rice plant withering. Vegetables are grown after rice, using residual soil moisture.

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

2.1.2 Crop genetic resources in SSA

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

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

The SSA region also possesses an enormous crop genetic resource potential. For example, edible yam accounted for 95.6% of the total world output of the crop (Okoli, 1991). A special mention should be made to Ethiopia, known as a Vavilovian center of crop domestication and diversity for several important plants; it has 12 potentially valuable crop plants, such as the root and tuber crops enset (*Ensete ventricosum*), anchote (*Coccinia abyssinica*), oromo dinich (*Coleus edulis*), the vegetable okra (*Abelmoschus esculantus*) and the legume crop yeheb (*Cordeauxia edulis*) (Demissie, 1991). Enset is the most important staple food in south-western Ethiopia, where its cultivation is restricted; the sources of food are the pseudostem and the corm. Tubers of oromo dinich are usually boiled and consumed as a vegetable. The seeds of yeheb are roasted or eaten raw; they have high protein content (13%), fat (11%) and starch (13%) (Anon, 1979).

Trends in crop genetic resource contributions within cropping systems.

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

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

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

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

IITA is also the major research center for bambara groundnut germplasm, which is still a neglected crop but has a high nutritional value (Goli *et al*, 1991).

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

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

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

Extensive research has also been carried out by NARS and by research institutions from the North (Canada, US, several European countries, etc.) working in SSA countries. Some typical examples are the evaluation and improvement of coffee by ORSTOM (Berthaud and Charrier, 1988), the improvement by NARS of rice lines tolerant to iron toxicity in Ghana (Owusu et al., 1999), and the release for large-scale production of two accessions of kafirs (sorghum races from South Africa) in Ethiopia (Menkir and Kebede, 1984).

However, following this trend, there was a drawback: it was observed that after the political independence of former African colonies, some edible wild plants, e.g., *Dioscorea praehensilis*, were forgotten and replaced by recently introduced species.

In addition, the success of crop genetic resources within agricultural systems in the SSA region is still controversial. Agricultural production has stagnated or declined in important food crops such as cereals, tubers, and legumes. Crop yields and productivity in most African countries are about the same as 20 years ago. In 1998, cereal yields in sub-Saharan Africa averaged 1 tonne ha^{-1}, 15% lower than the world average of 1.2 tonnes ha^{-1} in 1965. Cereal yield was stagnant around 1 tonnes ha^{-1} from the 60s to 2000 in the SSA region (Eicher et al., 2005). A question which has been raised is, “are the farmers using improved crop genetic resources? “ Improved genetic resources were released by international research centers and NARs through preliminary varietal trials (PVT), extension services and pilot farmers. An impact study of new extra-early maize varieties adapted and released in the Sudan savanna of Nigeria was completed; the adoption rate (14%) was found to be low (IITA, 2004). Scarcity of seed, and little seed exchange farmer-to-farmer were evoked as the reason for low adoption.

Farmers have limited access to seeds of newly bred modern varieties. The supply of breeder/foundation/certified and commercial seed of varieties preferred by farmers or required by the markets is limited. Seed demand is also uncertain and weak; thus, seed production is not profitable. There is poor integration between seed and product markets; the returns on investment are low (Ntare et al., 2005). Because conventionally improved genetic crop resources are only one component in crop yield potential, their utilization within the traditional production system is not well aligned with the economic context.

To ensure food security in the SSA region, the widespread adoption of improved crop genetic resources requires favorable government policies, and profitable markets for crop production. Seed regulations are currently inconsistent between the the national and sub-regional levels. Harmonization of seed regulations may facilitate the movement of improved seeds within the subregion, could help maximize the use of limited technical and infrastructural capacities and reduce unnecessary duplication. Seed delivery for promising genetic resources can be strengthened through regional participatory approaches. Potential food crops in the SSA region should be preserved and evaluated for important characteristicssuch as food value and ability to withstand stresses, and protected from genetic erosion by natural calamities such as drought and desertification.

Recently WASNET (West Africa Seed Network) and EASCOM (East Africa Seed Committee) were created as regional structures to promote seed development at local, national and regional levels in the frame of NEPAD.

Recent trends suggest the use of novel GMO (Genetically modified organism) and non GM technologies for improving crop genetic resources, for example tissue culture for some crops like plantain banana and anther culture for rice (Dhlamini, 2006). GMO has one or more genes from another organism in its genetic material (FAO, 2004b). Commodities around the world for which GMO varieties are available for commercial production include maize, cotton, canola, Irish potatoes, tomatoes, papaya, squash, soybeans and rape (ASARECA, 2006c).

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

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

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

2.1.3 Crop production systems, quality of production and productivity

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

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

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

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

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

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

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

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

System of Rice Intensification. This rice production system was developed in Madagascar in 1990 by Fr. Henrie de Laulanie and is gradually diffusing to other countries in SSA (Uphoff et al., 2002). SRI requires good water management to ensure good rice production, and recommends that rice paddies be kept drained during the day, with water added at the end of the day or at night to maintain soil moisture (Uphoff et al., 2002). In the system, rice is transplanted as very young seedlings that have only two tiny leaves with wide spacing of 25 x 25 cm, 33 x 33 cm, or 40 x 40 cm depending on soil types. Normal agronomic practices including early weeding and timely fertilizer application are necessary.

Examples of Major Food and Cash Crops in SSA

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

The apparent decline in groundnut production in SSA has been due to non adoption of improved groundnut varieties, timely and appropriate use of farm inputs, high plant population, and good crop husbandry (Schilling and Misari, 1992). Decline in groundnut production can also be linked to low world market price due to substitution by soybean and sunflower oil. To obtain a high plant population, planting should be at two seeds per stand and an intra-row spacing of 25 cm. Other factors include unfavourable climatic conditions characterized by frequent droughts, high temperatures and decline in soil productivity due to continuous cultivation. Increase in grain yield has resulted from the use of pest resistant and high yielding varieties, application of high plant population, and appropriate cultural and pest control measures made available through agricultural knowledge, science and technology (AKST). If these production measures are maintained, continued increase in crop production would be sustained.

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

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

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

Sorghum grain yields in SSA had been low up to the first half of the 20th century, with yields of between 500 to 800 kg/ha (Sarma and Nwanze, 1997). The main factors responsible for this low yield have been insect pests, diseases, weeds (especially the parasitic weed, *Striga hermonthica*) and severe drought. This has contributed to addressing the imbalance between food production and the ever-increasing population in SSA.

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

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

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

Mean cowpea grain yields in traditional intercropping systems ranged from 0 to 132 kg ha^{-1}, depending on the fertility level of the fields (Van Ek *et al*., 1997), compared with a sole cowpea yield potential of 1,500 to 3,000 kg ha^{-1} under optimum management (Muleba and Ezumah, 1985).The use of improved cowpea varieties has also contributed to increases in production. Other reasons for increased cowpea production have been an increase in harvested area, high plant population, and good management of insect pests and diseases. Drought stress and poor soil fertility have been important factors that have resulted in reduced cowpea yields.

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

The production constraints for horticultural crops in SSA include insect pests and diseases, the non-availability of improved high yielding plant varieties, and crop husbandry and cultural practices. Horticultural crops have exacting requirements necessary to produce high quality and value products for export. If addressed, these production constraints should lead to increased production of high quality horticultural crops.

Coffee. Coffee is an envigorating stimulant taken as a beverage worldwide. Owing to its high market price coffee is grown by farmers in SSA mainly for export. As a cash crop, it has contributed to improving the economic status of many resource-poor farmers in SSA. Both Arabian and robusta coffee, which are high quality, are cultivated in many areas in SSA. Coffee was established in SSA towards the end of the 19th century. Coffee production during this period and up to the first half of the 20th century was small scale and mainly practiced by small holders. Coffee production continued to increase gradually over the years with the small holders playing an important role in overall production. In Kenya, for instance, coffee production increased from 14,000 to 45,000 tonnes from 1952- 1966. Coffee production in SSA in the 1960s was 1.1 million tones, decreasing slightly in the 1970s before an increase to 1.2 million tonnes in the 1980s (FAO, 2004c). Production figures have remained more or less consistent since then. East Africa has consistently been the major producer of coffee in SSA with Ethiopia and Uganda as the lead coffee producing countries (FAO, 2004c).

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

2.1.4 Harvest and postarvest management

Storage of agricultural products may be done for consumption on a future date or for economic reasons to fetch more money when sold in times of scarcity. Agricultural products can be stored to provide seeds for subsequent planting. Government may also store surplus agricultural products for price stabilization by releasing the products in times of scarcity (Dike, 1994). In spite of the advantages of storage of agricultural products, insect pests and diseases are major limiting factors.

Several storage insect pests start their infestation in the field, which are carried into the store (Ajayi and Lale, 2001). Timing of harvest has been reported as a cultural method that can be employed in the control of storage insect pests (Olubayo and Port, 1997; Kabeh and Lale, 2004). Crops that are promptly harvested at maturity are less attacked by storage insect pests than those that are left longer in the field after maturity. The application of timing of harvest as a conscious effort to control storage insect pests was not in practice in traditional farming systems, employed through the early half of the 20th century. Prompt harvesting of crops at maturity has been recommended and in practice since the latter half of the 20th century, resulting in better food security.

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

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

The reasons for efforts at good postharvest management include the need for keeping good quality seed for planting, poor producer price immediately after harvest and government food security policies. AKST has made available several options, which can be used individually or in combination with postharvest management. These measures, which secure the harvest, ensure availability of food and reduction of poverty.

In SSA, the use of an integrated approach in postharvest management has not been a common practice, especially with the small holder farmers who produce the bulk of crops in the region. The reasons for this are mainly due to poverty and the lack of education. The training of farmers through Farmer Field Schools, for example, and the provision of soft agricultural loans, could go a long way in improving the technical know-how and financial status of these farmers. Some Governments in SSA have in the past and are currently providing agricultural loans to farmers, but these loans are hardly sufficient to meet farmers demand. Farmer Field schools, since their establishment, have been supported by the FAO and are currently operated in small scales in a few countries in SSA. In the more advanced countries of the world, farmers are literate and knowledgeable of available technologies in the management of postharvest pests. They also have the financial resources to obtain the necessary inputs for containment of these pests.

Considering economic constraints within SSA, improvements on existing local and traditional knowledge currently available to most resource-poor farmers in the region should be encouraged as a low-cost option for improvements to productivity.

2.1.5 Pest and disease management

Agricultural production in sub-Saharan African agroecosystems is greatly affected by pests. The pests and diseases affecting crops in this region are insects, nematodes, fungi, rodents, birds, weeds, viruses, bacteria, etc. Losses to pests and diseases are a serious limitation to the productivity of farming. The parasitic weed *Striga hermonthica* commonly known as "witchweed" infests as much as 40 million hectares of farmland in SSA and causes losses ranging from 20% to 100% and (AATF, 2005).

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

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

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

A wide range of regulatory options exists, including outright bans or severe restrictions on chemicals, alternatives and emissions controls. Legislation and associated regulations comprise an important component of national chemicals management. Their management requires a sense of priorities, a spirit of co-operation and a desire to anticipate and prevent problems rather than simply react to them.

In the mid-1980s, developing countries accounted for about one-fifth of global consumption of pesticides, of which SSA countries accounted for only 4% (FAO, 1995). Economic and social constraints have kept pesticide use in Africa the lowest in the world. Africa’s share has remained around 2% in recent years, with annual pesticide imports fluctuating between US$ 486-580 million over the period 1995-2000 and with import values estimated at US$503 million in 2000

(FAOSTAT, 2005). The use of pesticides in Africa continues to be extremely low relative to the global pesticide market. With the more recent trends of globalization and trade liberalization, especially in agriculture, the use of these chemicals may be intensified. Although most farmers cannot afford to use chemical pesticides, those who use them often apply wrong doses using improper procedures. In general, farmers in SSA lack basic agricultural training and this is aggravated by illiteracy that makes it impossible to read or follow complex pesticide label instructions.

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

Some of the most hazardous pesticides, as determined by the WHO are widely used in SSA. Sixteen such products were documented on the market in Benin in 1999, 25 in Ghana (PAN Africa, 2000), and 45 in Senegal (PAN Africa, 1999). The European Union decided in 1999 to ban imports of Nile perch from countries bordering Lake Victoria in East Africa, after reports of gross and widespread misuse of pesticide to catch fish in the Lake (EC, 1999). Many cases of poisoning, including at least 70 deaths in the 2000 cotton-growing season and 24 in the 2001 season (Ton et al., 2000) were reported in Benin. Endosulfan, an organochlorine insecticide (WHO Class II, moderately hazardous), was identified as the cause of most of these cases. Some pesticides are so persistent that they move far and wide, remaining in the environment for decades, and accumulate in fish, animals and humans, causing a range of ill effects (PAN Asia and the Pacific, 1999). They may have tended to destroy natural predators of pests and to disrupt natural immunity in both animals and plants. Another danger in African countries stems from out-of-date pesticide stocks, in many cases left over from past anti-locust campaigns. Countries generally stockpiled pesticides in order to better prepare for a further invasion. At the end of the 2004 locust plague, for example, Mali was still holding 75,000 litres of pesticide in reserve, (Kuiseu and Thiam, 2006) fearing the arrival of further locust plagues. Over 50,000 tonnes of obsolete stocks have accumulated in African countries as well as tens of thousands of tonnes of contaminated soils according to the Africa Stockpiles Programme (ASP). This programme was set up to address stockpiled pesticides and Pesticide Action Network (PAN) Africa has played an active part in its works since it began.

Small-scale farmers represent a large proportion of the farming population. Their crop protection strategies such as burning, use of crop diversity, intercropping, use of genetically resistant crop varieties and weed control practices, have recently drawn attention (Hussey, 1990; Kirkby 1990) and it is now understood that any new research results must fit into a traditional agroecosystem in order to be adopted by farmers (Neuenschwander, 1993). Integrated Pest Management (IPM) involves the integrated use of a range of pest (insect, weed or disease) control strategies in a way that not only reduces pest populations to satisfactory levels but also is sustainable and nonpolluting. Organic agriculture avoids the use of all synthetic fertilizers and pesticides. In Ghana IPM was adopted as a major component of agricultural policy in the early 1990s via the Ghana National IPM Program. The hurdle of adoption has been tackled using participatory methods of extension; one such project was highly successful in allowing farmers to reduce inputs costs, mostly due to reductions in insecticide use, while maintaining and often increasing vegetable yields and incomes. This requirement for farmer training in IPM is reflected in initiatives around the continent for key crops, many based on participatory methods and the Farmer Field Schools.

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

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

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

2.1.6 Processing and value addition

Processing is an approach (or an operation) used mainly for two purposes: reducing post harvest losses and producing convenient products. While processing, a material is transformed from one stage to another and hence its value is improved. On the other hand, value addition is a deliberate operation involving the use of different materials and processes to produce a totally new and different product.Both the conventional processing and the strategic value addition approaches make use of science and technology developments.

There are two clear types of processing: traditional and improved/industrial methods. Although the evolution and drivers of processing and value addition to crops may not be easily established, traditional processing may be as old as humans. People who lived a life of hunting and gathering used to smoke/dry meat in order to preserve it. Fermenting of food staples is a widely used traditional method in West Africa, and is still being disseminated to communities in other countries. Using biochemistry, physiology, physics and engineering knowledge, traditional methods of processing have been gradually improved upon (Asiedu, 1989) and have contributed to the development of industrial methods.

Food security, nutrition improvement and urbanization seem to be among key drivers to processing of food crops while income generation contributed as a driver to the processing of nonfood crops or/and production of nonfood products from food crops. With regard to the need to contribute to food security, food staples processing was initiated and still continues mainly to play a role in reducing post harvest losses.This is exemplified by the processing of cassava into forms like Gari, flour and chips. In these forms, cassava is stored or preserved for a longer time than fresh tubers, and can be kept over bumper periods to be used during food lean seasons. The importance of processing to reduce post harvest loses is acknowledge through the fact that results of the green revolution did not alleviate the population-food imbalance problem, as about 25% of food grown in the tropics is lost before utilization (Asiedu, 1989). The processing of both human food staples and animal feed can lead to value-added wholesome and nutritious foods that can be safely packaged for convenience. Several crops (direct produce or residues) are processed into different types of animal feed with greater nutritional value than individual fodder crops.

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

While traditional methods have been used to transform foodstuffs from one state to another, the products are usually not of optimum quality and standards. Inconsistency is common in products from the same or various processors, a problem being addressed gradually with continuous innovation and improved technologies. For example, cassava is processed into different food products in West Africa, and into industrial (nonfood) products such as starch and alcohol and flour used in adhesives in many other countries. The traditionally produced flour varies in colour, level of fermentation and is contaminated with dirt. Through AKST, traditional processing methods were improved by centrifuging the grated stage of cassava, drying with hot air driers, and sieving, thus improving the quality of flour by eliminating fermentation, contamination and avoiding colouration. AKST also contributed to the production of alcohol from the processing of cassava.

The influence of AKST in value addition and the utilization of crops is increasing, particularly in the field of biotechnology. However, there is still great need for more innovation in the area of starter cultures for fermented foods, namely, their development, storage and production sustainability. There is perceived need for using/applying genetically Engineered (GE) microorganisms in African fermented foods.

Crops widely processed across SSA include cassava, maize, soya bean, coffee, groundnuts. Processing of oil palm, coconut palm, cocoa is dominant in West Africa. Processing of sorghum and millet is across SSA but mainly by traditional methods and almost entirely for human consumption. Industrially, but at a small scale, sorghum is known to be processed to malt and beer (opaque beer) in South Africa (Asiedu, 1989). In Uganda, a purposively bred sorghum variety is processed into a beer.

2.2 Livestock and Wildlife Systems in SSA

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

Their overall role in environmental sustainability is contested with some researchers maintaining that livestock are detrimental to the environment (Breman, 1995; Dube and Pickup, 2001; Fuhlendorf et al., 2001; Hein, 2006).

2.2.1. Animal genetic resources

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

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

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

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

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

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

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

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

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

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

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

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

Technologies for management of animal genetic resources. In most sub-Saharan African countries, the tools used in the development of domesticated livestock are record-keeping and individual identification for breeding purposes. However, use of these tools is limited only to state farms and few smallholder farmers that keep crossbred animals provided by NGOs. In some government research and multiplication farms, the only breeding technologies used are electronic databases, genetic evaluation software and, artificial insemination (Das and Mbaga, 2002). Even these technologies are not widely used, limited to only a few researchers.

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

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

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

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

2.2.2 Typology of livestock production systems

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

The productivity of these commercial enterprises is high (Sere and Steinfeld, 1996; Delgado et al., 1999; Spencer et al., 2003; Devendra et al., 2005), but their land area is limited. Though current and projected productivity levels lag behind world averages (FAOSTAT, 2005), there is potential to increase productivity per animal unit in SSA through improved genetic resources and disease management and eradication, including gene-based technologies (Makkar and Viljoen, 2005).

On the downside are the potential environmental and human health hazards posed by these urban and peri-systems (UNDP, 1996; Delgado et al., 1999; Dunstan et al., 2003; Devendra et al., 2005), especially where laws and by-laws regulating livestock production are weak or nonexistent. This presents an opportunity for AKST to provide policy options and goods and services to avert the risks posed by these systems.

2.2.3 Trends in productivity, processing, marketing and value-addition

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

Livestock and wildlife are important to SSA country economies. For example, the livestock subsector is responsible for over 30% of the agricultural gross domestic product (GDP) and more than 50% of agricultural labor. The wildlife sector, on the other hand, is worth US $7 million with an annual growth rate of 5% (Wambwa, 2003). However, the productivity of SSA livestock in terms of immediate products is low in comparison to world averages and projected to remain so for the next 20 or so years (Table 2.5) unless there are major technological and policy interventions. Beef production is 20 times less while milk production is about 40 times less than world averages and pig and poultry products do not fare any better.

The protein consumption from livestock in SSA has remained low, with an average of 9kg meat and 23 kg milk per person per year, compared to the developed countries, with an average of 76kg and 145 kg respectively (Delgado et al., 1999). On the other hand, in some SSA countries, the proportion of wild meat in total protein supplies is quite high (84% in Nigeria, 75% in Ghana, 70% in Liberia and 60% in Botswana (FAO, 1990), thus complementing livestock protein. However, wildlife consumption is often unappreciated, unrecorded and therefore underestimated (Asibey and Child, 1990).

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

SSA, so as to take advantage of income potentials from the increased demand for livestock products (Table 2.5).

[Insert Table 2.5]

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

2.2.4 Livestock and wildlife pests and diseases

Although the population of livestock has increased significantly over the years (Fig. 1) to enable adequate protein supply to SSA countries- the ratio of cattle to human population for 2005 was estimated at 1:4 (212m cattle: 750m people) (FAOSTAT, 2005)- most of these animals are of poor health and concentrated in a few areas.

One of the major constraints to the development of the livestock and wildlife industries in SSA are pests and the diseases they transmit (Bengis et al., 2002). Therefore, for sustainable livelihood security and to advance development and sustainability goals in SSA, improvement of the livestock and wildlife industries is essential. One step toward this is appropriate control of livestock and wildlife pests and diseases.

2.2.4.1 The livestock/wildlife interface in sub-Saharan Africa.

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

i) Infectious diseases associated with wildlife known to cause diseases in domestic livestock. The single most important factor responsible for causing an outbreak of any of these diseases is probably the direct or indirect (vector) contact of infected wild hosts or populations with susceptible domestic animals at the interface of their ranges, where mixing has occurred on common rangeland, or, where other resources, like water are shared. Diseases under this category are foot and mouth disease (FMD), African swine fever (ASF) and classical swine fever (hog cholera), trypanosomiasis, theileriosis or corridor diseases, African horse sickness, Rift Valley fever (RVF), bluetongue, lumpy skin diseases, malignant catarrhal fever and, Newcastle disease, (Bengis et al, 2002).

ii) Multispecies diseases that affect both livestock and wildlife. Transmission of these diseases can occur in both directions, although in certain regions, dominant role players have been identified. These diseases are generally fatal to both wildlife and livestock and, are frequently zoonotic. Examples of such disease are anthrax, rabies and brucellosis (Bengis et al, 2002).

iii) Alien diseases that infect wildlife and domestic livestock. Some of the best examples in this category are certain diseases historically alien to SSA, that were probably introduced into the African continent with the importation of domestic livestock from Europe and Asia during the colonial era. Indigenous African free-ranging mammals are generally susceptible to these foreign agents and significant morbidity and mortality may be encountered in both wildlife and domestic livestock. Such diseases include rinderpest, canine distemper, bovine tuberculosis, African horse sickness and African swine fever (Bengis et al., 2002).

2.2.4.2 Selected diseases and pests of livestock and wildlife

To understand the impact of AKST on livestock and wildlife pests and disease management over time, examples of a few important diseases and vectors are discussed below.

Rinderpest. Rinderpest is a viral disease introduced into Eritrea from India during the pre-colonial era either by the Italian army in 1887/1888, or by a German military expedition that brought infected cattle from Aden and Bombay to the East African coast. The disease killed more than 90% of all cattle population and wildlife (Henning, 1949). However, during this pre-colonial era, even without advanced technology, cattle farmers in South Africa managed to contain rinderpest through immunization of cattle, by using the bile of animals that died of the disease and, by end of 1898, the disease was under control and temporarily disappeared from South Africa (Henning, 1949). However, because immunisation of cattle against rinderpest was limited to South Africa and, because sub-Saharan Africa lacked strict national borders, the disease resurfaced again in 1901 (Henning, 1949). The situation remained unchanged during the colonial period, making rinderpest one of the most devastating diseases of both livestock and wildlife. Advances in AKST have created efficient vaccines to contain rinderpest and, currently, the disease is no longer a threat. Globalization has also played an important role and now, under the global rinderpest eradication programme (GREP), a total of 25 SSA countries have managed to declare themselves or zones within their country free from this disease. In addition, six SSA countries have been declared rinderpest-free by the World Organisation for Animal Health (OIE) (OIE, 2007).

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

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

Theileriosis was first recognised in Southern Africa during the colonial period, when it was introduced at the beginning of the century with cattle imported from eastern Africa, where the disease has been endemic for centuries. Although the disease was eradicated from most southern African countries, it has persisted in eastern Africa and, it has expanded in recent years, particularly at the periphery of its distribution in Sudan and Zambia (Henning, 1949).

During the colonial era, cases of ECF were treated by inoculation of susceptible cattle with blood from a sick or recovered animal. Although this method worked in some cases, its effect on overall disease control was limited (Henning, 1949). Different communities in SSA have practiced traditional veterinary medicine in the treatment of ECF since pre-colonial times and, some of the remedies have been quite effective (Bizimana, 1994; Minja, 1994; Sindiga et al., 1995; Kambewa et al., 1997; Wanyama, 1997; Dery et al., 1999; Minja and Allport, 2001). The colonists introduced dipping schemes in early 1900, whereby cattle were dipped in acaricides to control the vector ticks, a practice which proved to be quite effective and has been in use up to now.

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

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

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

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

African governments developed a new initiative, known as the Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC), which seeks to employ an area-wide approach and appropriate fly suppression methods to eradicate tsetse and, ultimately, create tsetse-free zones (Kabayo, 2002). Efforts have also been made at the international level, whereby the Programme against African Trypanosomiasis (PAAT) has been initiated. PAAT, officially established in 1997, forms the umbrella for an inter-agency alliance comprising FAO, IAEA, AU/IBAR, WHO, research institutions, field programs, NGOs and donors. PAAT treats the tsetse/trypanosomiasis problem as an integral part of development and poverty alleviation, assuring positive and lasting results in trypanosomiasis-affected areas. The overall goal is to improve the livelihood of rural people in the 37 tsetse affected countries of SSA (http://www.fao.org/aga/againfo/programmes/en/paat/about/html).

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

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

In Africa, bovine tuberculosis was most probably introduced with imported dairy and

Bos taurus type beef cattle during the colonial era. This disease is now widespread and prevalent in 33 of 43 (80%) African member countries of the World Organisation for Animal Health (OIE). Bovine species are natural hosts to the disease, but a wide spectrum of domestic and wild animals, as well as man, can be infected (Ayele et al., 2004).

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

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

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

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

2.3 Forestry/Agroforestry and Forest Products

2.3.1 Forest genetic resource potential and biodiversity management

Natural forests are being cleared (deforested) while the extent of plantation forests is increasing (FAO, 2007). In 2000, total world forest resources were estimated to be 4.4 billion ha with forests in Africa comprising 627 million ha (MA, 2005). The extent of global corests was calculated at under 4 billion ha, or 30% of the world's land area in 2007 (FAO, 2007). According to current estimates, 9.4 million ha of the the world forests are converted to other land uses (i.e. deforested) every year in the 1990s, (MA, 2005; FAO, 2001; UNHCR, 2004). Tropical forests cover only 7% of earth's land surface (Myers, 1988) yet contain, by some estimates, at least 50% of all species, with the Amazon Basin having the richest biota on Earth. Tropical forests are being depleted faster than any other ecological zone, and the loss of biodiversity has been well documented. Some have claimed there is strong evidence that the earth is in the opening stages of an extinction crisis (Raup and Sepkosky, 1984; Myers, 1986; Raven, 1987; Wilson, 1988). Net annual forest losses are calculated between 7.3 and 9.4 million ha^{-1}, with the African continent contributing close to 50% of these losses (MA, 2005; FAO, 2007).

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

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

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

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

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

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

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

2.3.2 Pest and disease management

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

2.3.3 Quality of produce and productivity

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

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

2.3.4 Timing of harvest and postharvest management

Timing of harvest/ postharvest management, including processing and the quality of products, value-addition, etc., or simply forest ecosystem management strategies require scientific knowledge. Science and technology outputs generally are not consumed by forest users. If current weaknesses in forest science and technology efforts persist, the gap between developed and developing countries in the adoption of sustainable forest management practices could grow. Limited application of scientific advances to a few élite segments of the forest sector will contrast sharply with the lag in the rest of the sector resulting from insufficient research and development efforts, especially in the management of indigenous forests and those catering to local needs. The narrow pursuit of commercial profits could increase society's vulnerability to unforeseen environmental and socioeconomic changes. There is an urgent need to strengthen scientific capacity, especially in countries where it remains poor such as in the Congo Basin countries. The signed statutes establishing the Conference of Ministers in charge of Forests in Central Africa (COMIFAC), in 2002, is an important step towards transboundary management policies of forests for sustainable development. Common views, common goals and joint efforts can lead to shared benefits within the sub-region (FAO, 2003b).

2.3.5 Processing, value addition and utilization

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

2.4 Fisheries and Aquaculture

2.4.1 Fish species/other aquatic species from fisheries and aquaculture for human consumption

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

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

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

In many SSA countries, capture fisheries have ill-defined use rights. The resource is usually owned by the state but managed as “regulated open access”. Thus, fishers could harvest any quantity of fish if they comply with regulations set by central or local authorities. It has been argued that community-based resources are not generally overexploited as predicted by Hardin’s “tragedy of the commons”. However, if the group using the resource is relatively unstable, if the members of the group do not have adequate information about the condition of the resource, and if information about the expected flow of benefits and costs is not available at a low cost to the resource users, there may be little incentive for the community to design rules to manage the resource (Ostrom, 2000). Unfortunately, there is free mobility of fish stocks across communities and countries. Moreover, some of the fisheries are characterized by unpredictable seasonal growth rates due to upwellings. In some cases, state institutions have enacted conflicting policies at different points in time, which inevitably created mistrust between fisheries departments and fishers. Furthermore, inadequate policies of regulatory authorities provide opportunity for self-interested fishers to use illegal fishing technologies. For example, mesh size regulations in multi-species fisheries, with small and large pelagic species, are considered illegitimate by many fishers and are therefore heavily violated in many fishing communities. Moreover, capture fisheries regulations are generally poorly enforced as a result of limited budgets in state institutions responsible for enforcement, corrupt enforcement officers who solicit bribes from violators and an unenthusiastic judiciary that assigns minimum or no punishment to violators of fishing regulations. Commercial fishers, who use fishing vessels compete with local fishers for inshore fish stocks, degrade habitat and interrupt the fish food chain (Sterner, 2003). This has often led to conflicts loss of property.

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

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

2.4.2 Aquatic ecosystems management and genetic resources/biodiversity potential

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

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

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

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

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

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

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

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

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

[Insert Box 2.1]

There are a number of potential challenges that confront aquaculture in SSA. These include the provision of information, training and credit, the availability of fishmeal and fish oil for cultivation and mitigating the likely environment impact of semi-intensive aquaculture. Substituting vegetable protein for fishmeal may result in a higher mortality rate and low rate of growth of several aquatic species (Delgado et al., 2003). Intensive aquaculture requires the use of compound feeds, pesticides, and antibiotics. The spillage of these substances into natural aquatic systems may negatively affect these ecosystems.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

2.4.3. Quality of produce, productivity

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

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

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

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

Fisheries and aquaculture in SSA offer a huge potential for sustainable development. Unfortunately, fish biodiversity, systematics, ecology, and conservation strategies are not well-known. Despite the fact that most SSA countries have signed the Convention on the Biological Diversity, AKST inputs remain negligible. Due to high biodiversity indices, the Congo Basin needs particular attention to fish biodiversity management. Ongoing work by the US NGO IRM

(Innovative Resources Management), American Museum for Natural History/ New York, and their local partner ERGS (Environmental Resources Management and Global Security) could be supported.

2.5 Bioenergy

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

African countries are the most intense users of biomass in the world and there is a strong correlation between the use of biomass as a primary energy source and poverty (Table 2.6). In the poorest countries the share of biomass in residential energy consumption can reach up to 90%. Similarly, within countries the use of biomass is heavily skewed towards the lowest income groups. In rural areas 92% of the population does not have access to electricity and thus has to rely almost entirely on biomass, LPG and kerosene to meet its energy needs (IEA, 2002).

[Insert Table 2.6]

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

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

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

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

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

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

2.6 Sociocultural Issues

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

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

A typical farm household in sub-Saharan Africa is illustrated below based on: the clear distinction between men’s and women’s roles, including management of different types of production, either individually or together; individual responsibility for mobilizing the factors of production, through barter or monetary exchanges, for individual or joint use; defined patterns for the exchange of goods and services among the household members; elaborate arrangements determining who makes decisions with regard to selling, consuming, processing and storing agricultural products.

Household, farming or enterprise activity Men: cash crops, large livestock Women: child rearing and household maintenance (including food preparation, gathering water and fuel), food and horticultural crops, small livestock, agroprocessing and trading (home based)
Farming tasks Men: clear land Women: plant, weed, process and store agricultural products
Separate fields and plots: Men and women each responsible for own inputs and controlled outputs
Jointly managed plots Men and women share labor input, use proceeds for family purposes

Land rights Men: ownership Women: insecure tenureship, determined by husband or male relatives
Input rights Men: right to resources such as land, labor, technical information and credit Women: access to these resources determined by men

In Kenya women reported that men were responsible for building the granary while women were responsible for hand digging, harvesting and transporting crops. Though tasks may be viewed as womens' or mens' in practice the divisions are blurred, with both men and women involved in many tasks (Pala, 1983).

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

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

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

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

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

In SSA new technologies have been introduced to increase agriculture production. These technologies are based on the use of agriculture inputs such as fertilizer, seeds and the associated extension services. Evidence suggests that in SSA women have less access to these inputs than men. Fertilizer use is dependent on 1) its availability for in the area in a timely fashion and 2) whether the farmer has the resources to purchase fertilizer (Doss, 1999). The impact of fertilizer use on productivity also depends on whether farmers apply it appropriately on their fields. Zambia presents a typical case of frequent non-availability of fertilizer in farming areas. Over the years farmers have bemoaned the non-availability or late delivery of inputs such as fertilizer and seed. Associated with this is the prohibitive price of fertilizer. Most farmers are not able to afford the required amount of fertilizer for maximum production. The situation gets worse for women who have difficulties accessing fertilizer and in instances when it is available, can ill afford to purchase due to their limited financial resources.

Gladwin emphasizes the importance of fertilizer subsidies as a means of increasing maize production among women farmers and increasing household food security. Gladwin sites examples from Cameroon and Malawi indicating how removal of subsidies has affected female farmers more than male farmers because they reduce the use of fertilizer on local maize (a woman's crop).

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

Access to and utilization of extension services has a bearing on agriculture production. Use of timely and appropriate extension services can result in higher yields (Saito and Weidman, 1990). However due to the social and cultural positioning of women it is evident that in most cases women do not get the benefits of extension services. Several factors account for this which include 1) poor timing for extension services provision 2) taboos surrounding male extension staff and female farmers interactions 3) low literacy levels amongst women compared to men 4) immobility on the part of women thus limiting their access to extension services 5) Language differences that can impede the communication of improved technology.

Some efforts to reach women through extension services have proved a success in Zimbabwe where a group approach was used in crop production, thereby attracting extension services. (Muchena, 1994). Many countries in SSA have great potential to produce food and traditional agriculture exports for themselves, their neighbors, the region and the international market. However Africa's vast potential is not tapped. One of the major factors among others is the issue of consistent and transparent institutions that are essential for organization in the agriculture sector.

The magnitude of institutional building in Africa is more daunting than it was in India in the 1960's when three major international organizations helped the country build a system of agriculture institutions (Eicher, 1999). Africa's post independence agrarian history has been characterized by two distinct phases of institutional expansion and reform. The public sector expansion phase took precedence between 1960 and 1985. The period from 1985 to 1999 can be described as a period of downsizing public universities, research institutions and extension services, privatizing parastatals and expanding foreign private investments and new forms of public/private partnerships (Eicher 1999).

In the expansion phase of the 1960's to 1985 all newly independent governments invested in educating its citizenry. At independence, Botswana had only 40 graduates. In 1960, 90% of agriculture researchers in Africa were expatriates. Governments later embarked on Africanizing the civil service, increasing school enrolments, constructing new universities. A case in point is Zambia where the first university was built through material and financial donations from the Zambian public. In Africa generally, thousands of students were sent abroad for BSC and graduate level training. Donors supported this human capital development through financing the construction of new universities and creating faculties of agriculture. The number of extension workers in SSA increased from 21,000 in 1959 to 57,000 in 1980; universities increased from around 20 in 1960 to 160 in 1996 (Eicher, 1999). The number of full time equivalent agriculture scientists increased from around 2000 in 1960 to 9000 in 1991.

Following this phase came the downsizing and restructuring phase. This was a result of the Structural Adjustment Programme which had imposed several conditionalities, among them downsizing the civil service, research and extension and higher education have been downsized and restructured and new private institutions (seed and fertilizer companies and universities) are now in stiff competition with public counterparts. In most countries universities are the weak links in the agriculture triangle because they are still in their infancy (between 20 and 30 years) and because they have experienced drastic cuts in their budgets.

The whole notion of privatizing the agriculture sector has had adverse effects on agriculture production. The capacity of the private sector to boost agriculture production has been under scrutiny and indications are that governments still need to play a significant role to allow for public private partnerships.