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COMPETE

Competence Platform on Energy Crop and Agroforestry Systems for Arid and Semi-arid Ecosystems - Africa

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Improved agricultural practices in farming systems of semi-arid and arid Africa in view of future possibilities for bioenergy production

Experiences from the COMPETE Network

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1 Introduction

1.1 Background

Agricultural production in Sub-Saharan Africa showed in average a low productivity and, especially in semi-arid and arid parts of the continent (IAASTD, 2008; IAC, 2004). This true for crop production as well as animal production systems, and average increases in productivity in recent years have been only moderate (IAC, 2004, FAOSTAT, 2008). At the same time, average incomes are often low with many people living below the poverty line and/or being food insecure, as in Sub Saharan Africa about 33% of the population are undernourished. Furthermore, access to energy is limited for parts of the rural population as about 9% of the rural population in Sub-Saharan Africa has no access to electricity and diesel is scarce for large parts of the population given the recent high prices.

Agricultural production levels, income and energy supply are obviously closely linked to each other. While agricultural production levels determines the income of people working in this sector and as consequence also access to energy, the availability of capital and energy influences realizable agricultural production level. Moreover, energy is often the key to other commercial activities that can increase income. The production of biomass for bioenergy is one of the possible solutions for these interrelated problems even though other measures to improve efficiency and income in agriculture (e.g. diversification of plant and livestock genomics, increased use of fertilizers and agricultural technologies, development of market and infrastructure) will be necessary. Bioenergy can also have negative environmental and social effects, such as centralization of agriculture without benefiting small, displacement of food production and subsequent food insecurity or use of scarce water resources; see (UNDESA, 2007; Ziegler, 2008). Possible benefits of biomass production are:

- The increase of income in the agricultural sector through the use of previously unused resources (e.g. intercropping, degraded land) or the production of high-value bioenergy cash crops.
- The provision of bio-energy in various forms, such as biomass for rural electrification, for commercial heat and electricity production, as fuel for use in engines and as transportation fuel.
- An increase in investment and capacity building in the agricultural sector leading to the application of best management practices and an increase in agricultural productivity

A direct link between biomass for bio-energy production and agricultural production of crops and animal products in general is the use of land (and water). The availability of land for the production of biomass in developing countries is determined by the demand on land for food production. With increasing population, food production and consumption in developing regions is expected to increase (FAO, 1995). Estimates by the Response Strategies Working Group of the IPCC indicate that the use of land for food production in developing regions (Asia, Africa and Latin America) will increase by 50% by the year 2025 (IPCC, 1996). In addition, the demand for biomass energy is also expected to increase with population increase. Estimates by the WEC indicate that by 2100, about 1,700 million hectares of additional land will be needed for agriculture, while about 690-1,350 million hectares of additional land would be needed to support biomass energy requirements (UNDP, 2000).

Thus, on the one hand, biomass production competes with agricultural production for land and water resources in case crops similar to conventional agricultural crops (e.g. sugar cane) are produced or biomass for energy is produced on land and with water that would have otherwise been used. However, given the fact that in large parts of semi-arid and arid Africa large additional areas of land are in principle available for agriculture (Watson, 2008), this competition does not necessarily need to have negative consequences on the production of food and food security even though negative impacts are possible.

In addition, advance in overall agricultural productivity can turn previously used agricultural land available for biomass production and some crops for bioenergy, such as jatropha, short rotation wood and fast growing grasses can be produced on marginal and/or degraded land with limited water use. Finally, the possibility to produce biomass for bioenergy in multiple production systems (e.g. intercropping of wood and maize or seasonal cropping of sugar cane and sweet sorghum, use of tree pods as fodder) is a further possibility to reduce land competition.

Therefore, the technical potential of biomass for energy production in Africa could large, if agriculture could be modernized. For example, a study of (Smeets, 2008) that investigated technical bioenergy potentials of wood energy crops in Sub-Saharan Africa could amount to about 31 EJ in 2050 without compromising the production of food. This estimate is based moderate improvements in agricultural production such as moving to a mixed animal production system and a high level input system in rain-fed agriculture, while an ultimate technical potential would amount to about the tenfold of biomass potentials.

1.2 Objectives

This report summarizes improvements in agricultural practices in semi-arid and arid Africa that could be relevant for the feasibility of energy production. This can either be food production systems for crops and livestock in which improvements could lead to a lower use of agricultural land for food or the possibility to use marginal land, food production system that allow for mixed production of energy and food and pure energy crop production systems.

In the past, many research projects and case studies have been undertaken in Sub-Saharan Africa with the goal to improve local livelihoods by providing higher economic returns, food security, risk minimization and/or conservation of the environment; see e.g. (UNDESA, 2008; IAC, 2004). The scope of this report is not to describe and evaluate all possible approaches for the improvement of agriculture in Sub-Saharan (semi-arid and arid?) Africa, but to summarize the experiences within the COMPETE network[1] From this overview, possibilities for 'best practice' agricultural systems with a large relevance to future bioenergy production are identified.

Section 2 summarizes the status of agricultural production in Sub-Saharan Africa, its current efficiency, its main production systems as well as main environmental impacts. Section 3 gives an overview of possible production systems for the improvement of agricultural management concentrating on aspects relevant to bioenergy. It starts with a general overview and then gives examples from the production of livestock, starch and sugar crops, oilseed crops and lingo-cellulosic energy crops. Finally, section 4 draws conclusions in view of important improvements in agricultural management that could enhance the production and use of bioenergy.

The primary source of biomass energy is woodfuel—firewood and charcoal—but agricultural residues and animal wastes are used to a lesser extent where woodfuel is unavailable. This biomass is mainly used for cooking and space heating. Efficiencies of such uses are often low. For example, fuelwood is mostly burned in simple 3-stone stoves with very low thermal efficiencies between 5-20% (Wiskerke, 2008). Other negative impacts of these traditional uses are the emissions of greenhouse gases from incomplete combustion, indoor air pollution and related health effect, overuse of wood resources and related deforestation and the mainly female labour needed for fuelwood collection; see Section 2.

Modern and improved uses of biomass for bioenergy is could be a possible solution to increase the efficiency of bioenergy use, to combat energy poverty especially of modern energy carriers such as transport fuels and electricity and to contribute to rural development. However, bioenergy can also have negative environmental and social effects, e.g. displacement of food production and loss of biodiversity.

However, barriers to bioenergy expansion are set by factors including the resource potential and distribution, the efficiency of biomass conversion technologies, public acceptability; and land-use and environmental aspects. Most of these barriers to the increased use of bioenergy could be overcome by developing and deploying cost-effective conversion technologies, by developing and implementing improved dedicated bioenergy crop production systems, by establishing bioenergy markets and organizational structures and by valuing the environmental e.g. by carbon financing.

[1] Competence platform on energy crop and agro-forestry systems for arid and semi-arid ecosystems in Africa

As a consequence, many development projects have targeted the use of biomass for energy while improving social and environmental conditions. This comprises the introduction of improved household stoves, the use of improved charcoal kilns and the use of modern bioenergy sources such as ethanol and biodiesel for transportation and the production of electricity from various sources. Other improvement options for household cooking are the switch to advanced fuels such as liquefied petroleum gas (LPG), electricity, and biofuels from vegetable oils, ethanol or biogas.

The objective of this report is to describe the state-of-the are of traditional biomass uses in Sub-Saharan Africa concentrating on the use of fuelwood, charcoal and agricultural residues as well as describing improved bioenergy systems for cooking and heating and for modern applications such as transportation fuels, process heat and electrification. Based on this recommendations on best practice bioenergy systems for Sub-Saharan Africa will be made within the COMPETE project.

2 Current agricultural production

2.1 Main crops and farming systems

One main characteristic of African agriculture is that it is very diverse. This is true for environments (soils, climate and water availability) as possible management systems (combinations of crops and livestock, scales, input.) Dixons et al. have summarized this diversity in distinct farming systems that are based on a variety of crops and livestock. Table 1 gives and overview of these systems.

Table 1: Farming systems of Sub-Saharan Africa (Source: IAC, 2004)

Farming System	**Land area** (%region)	**Agric. Population** (%region)	**Principal livelihoods**
Maize mixed	10	15	Maize, tobacco, cotton, cattle, goats, poultry, off-farm work
Cereal/ root crop mixed	13	15	Maize , sorghum, millet, cassava, yams, legumes, cattle
Root crop	11	11	Yams, cassava, legumes, off-farm income
Agro-pastoral millet/ sorghum	8	9	Sorghum, pearl millet, pulses, sesam, cattle, sheep, goats, poultry, off-farm work
Highland perennial	1	8	Banana, plantain, enset, coffee, cassava, sweet potato, beans, cereals, livestock, poultry, off-farm work
Forest based	11	7	Cassava, maize, beans, cocoyams
Highland temperate mixed	2	7	Wheat barley, teff, peas, lentils, broadbeans, rape, potatoes, sheep, goats, cattle, poultry, off-farm work
Pastoral	14	7	Cattle, camels, sheep, goats, remittances
Tree crop	3	6	Cocoa, coffee, oil palm, rubber, yams, maize, off-farm work
Commercial large- and smallholder	5	4	Maize, pulses, sunflower, cattle, sheep, goats, remittances
Coastal artisanal fishing	2	3	Marine fish, coconuts, cashew, banana, yams, fruit, goats, poultry, off-farm work
Irrigated	1	2	Rice, cotton, vegetables, rainfed crops, cattle, poultry
Rice/tree crop	1	2	Rice, banana, coffee, maize, cassava, legumes, livestock, off-farm work
Sparse agriculture (arid)	18	1	Irrigated maize, vegetables, data palms, cattle, off-farm work
Urban based	<1	3	Fruit, vegetables, dairy, cattle, goats, poultry, off-farm work

As a consequence of the diverse farming systems, main crops are diverse and yields and inputs show broad ranges, see Table 2. Maize is by far the most important staple crop in Eastern and Southern Africa in terms of area harvested. Other important crops in Eastern Africa are sorghum, cassava and beans, while in Southern Africa wheat, sugar cane and millet play an important role. Also in Middle Africa maize plays together with cassava a main role. In Western Africa, the main crops are millet, sorghum and cow peas.

Table 2: Main crops: area harvested (1000 ha) in 2006 (Source: FAOSTAT, 2008)

Crop	Eastern Africa	Southern Africa	Western Africa	Middle Africa
Beans, dry	3492	71	306	958
Cassava	3232	0	5528	3344
Cocoa beans	31	0	4957	453
Cotton lint	1163	41	2488	639
Cottonseed	1478	47	2484	669
Cow peas, dry	510	15	9288	125
Groundnuts, with shell	1338	58	4773	1600
Maize	11735	2295	7589	3303
Millet	1541	267	14638	1482
Oil palm fruit	7	0	4060	354
Plantains	2421	0	1267	613
Rice, paddy	2027	1	5600	570
Seed cotton	1369	37	2486	626
Sorghum	4253	118	12319	1509
Sugar cane	576	472	123	230
Sweet potatoes	1634	16	1218	275
Wheat	1913	778	75	12
Yams	32	0	4142	167

2.2 Yields

Historic development of crop yields in Sub-Saharan Africa show only moderate increases in the past 40 years, see Figure 1. However, growth rates of yields varied strongly between region and crops. Overall yields of cocoa, cow peas, millet, sorghum, wheat and yams have increased strongly in the beginning of the 21st century in Africa including North Africa. However, yields of some crops including staple crops have also decreased in some regions of Sub-Saharan Africa; see Table 3.

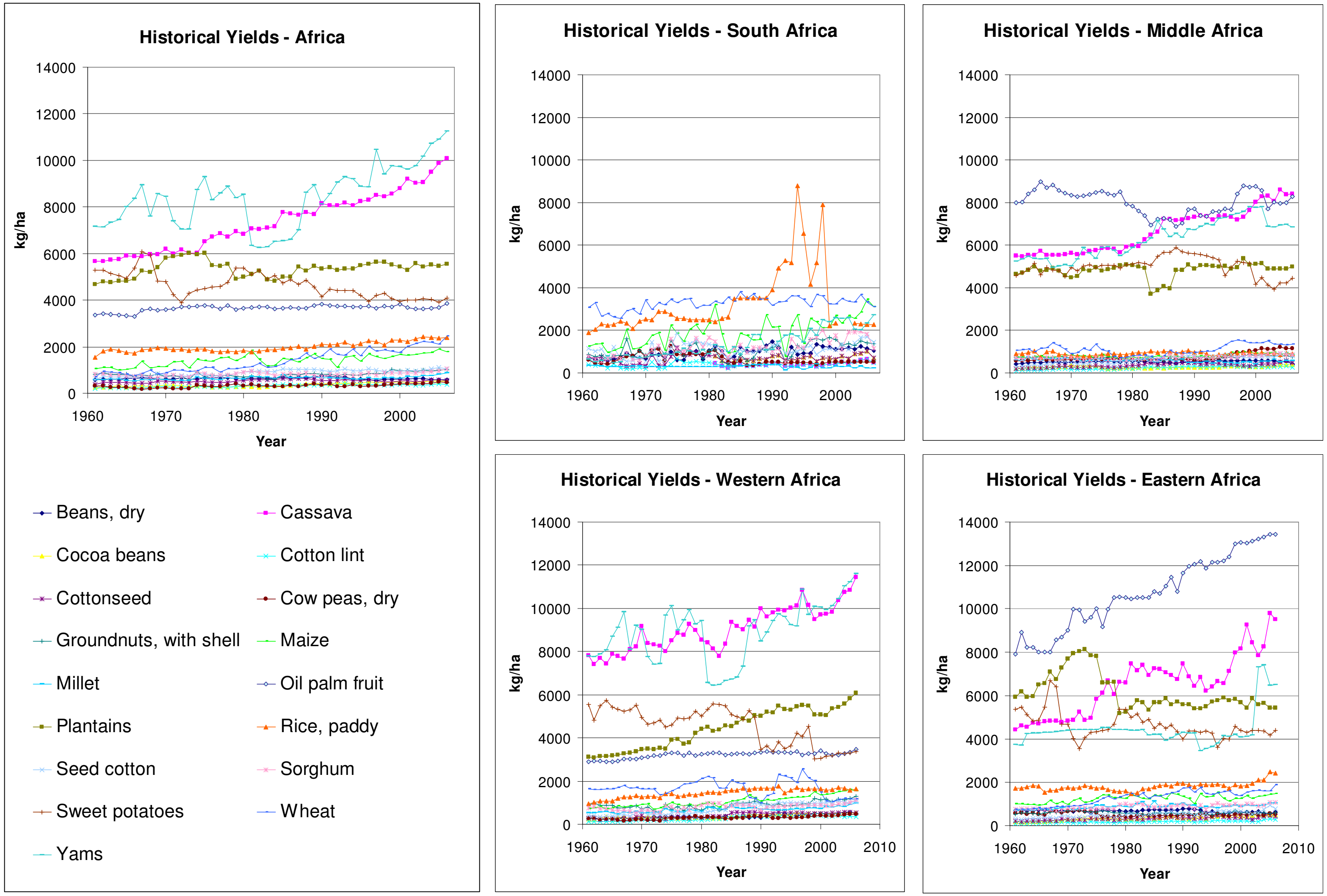

Figure 1: Historic crop yield development in Sub-Saharan Africa (Source: FAOSTAT, 2008)

Table 3: Annual growth rates in % of agricultural yields in sub-Saharan Africa (Source: FAOSTAT, 2008)

Crops	Eastern Africa	Southern Africa	Western Africa	Middle Africa	*Total Africa*	Eastern Africa	Southern Africa	Western Africa	Middle Africa	*Total Africa*
			1961-2006					*2001-2006*		
Beans, dry	-0.3	0.9	1.2	0.0	*0.0*	-0.1	-1.4	1.2	-6.6	*-1.4*
Cassava	1.7	0.0	0.8	0.9	*1.3*	0.6	-1.4	3.3	0.3	*1.9*
Cocoa beans	2.0	0.0	1.7	1.2	*1.7*	2.2	-2.6	2.6	6.1	*3.0*
Cotton lint	2.3	0.5	2.3	2.1	*1.5*	5.5	-1.4	-1.0	-3.9	*0.1*
Cottonseed	1.6	-0.2	1.5	2.2	*0.9*	2.9	-2.6	1.0	3.2	*0.3*
Cow peas [a]	-0.2	-0.4	1.0	1.6	*0.8*	0.9	0.0	4.0	0.1	*3.6*
Groundnuts [b]	0.2	1.0	0.8	0.1	*0.5*	-1.4	0.9	1.8	-2.4	*0.9*
Maize	0.9	2.0	1.7	0.3	*1.2*	1.5	6.0	2.4	-1.1	*1.6*
Millet	0.9	-1.0	1.3	-0.2	*0.9*	2.4	-5.5	4.0	0.9	*4.2*
Oil palm fruit	1.2	0.0	0.4	0.1	*0.3*	0.6	0.0	1.2	-0.7	*0.9*
Plantains	-0.2	0.0	1.5	0.2	*0.4*	0.0	0.0	3.9	-0.6	*1.0*
Rice, paddy	0.8	0.4	1.3	0.1	*1.0*	5.4	n/a	0.6	-1.0	*1.5*
Seed cotton	2.0	0.5	2.1	2.4	*1.4*	4.2	1.4	0.9	1.3	*1.5*
Sorghum	0.8	0.9	0.9	0.5	*0.6*	1.7	0.1	5.9	0.7	*3.2*
Sugar cane	0.0	-1.1	1.5	-1.4	*-0.3*	-3.3	0.1	-2.7	-0.9	*-0.9*
Sweet potatoes	-0.4	0.0	-1.1	-0.1	*-0.6*	0.5	-2.3	1.5	-0.2	*0.5*
Wheat	2.1	3.3	-0.7	0.5	*2.9*	3.9	1.3	1.7	-1.0	*4.0*
Yams	1.2	0.0	0.9	0.6	*1.0*	9.6	0.0	3.2	-2.5	*3.2*

[a] dry, [b] with shell

Root crop yield showed a modest increase in farming systems in which they where a primary commodity and cereal yields grown have mainly grown significantly in irrigated and commercial farming systems. (IAC, 2004)

For livestock production, even less research and implementation of better management practices have been carried out. As a result, productivity in livestock production systems lags behind world averages. (IAASTD, 2008) Unfortunately, there are no overview statistics on the historic development of feed conversion efficiencies.

2.3 Production systems

As agricultural production is very diverse ranging from rain fed smallholder systems to irrigated commercial systems, input levels differ widely. In general, however, input levels in Sub-Saharan Africa are very low compared to world averages and these inputs are a main reason of for low yields. According to (Kalirajan and Shand, 2001) about 67% of the yield gap between environmentally attainable yields and actual yields is due to not following best practices

The average use of fertilizers in Sub-Saharan Africa is about 9 kg N and 6 kg P per ha, see also Table 1 while requirements for these fertilizers are in the range of 60, 30 kg and the global average use of all fertilizers is about 96 kg/ha. (IAC, 2004, IAASTD, 2008) Therefore, nutrient deficiency is the main reason for low yields and especially for green manure (legumes) phosphor deficiency plays a major role.

Table 4: Average use of fertilizers on arable land and permanent crops (kg/ha) (Source: FAOSTAT, 2008)

	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)
Eastern Africa	6	4	1
Middle Africa	1	0	1
Northern Africa	50	12	2
Southern Africa	23	12	3
Western Africa	2	1	1

Water use efficiency, i.e. irrigation water that reaches root zone, is only about 20-30% in sub-Saharan Africa, while 50% wood be a good benchmark for the region. With capital investment in irrigation even larger efficiencies can be reached, e.g. 70-80% for sprinklers. Typically, yields and income are 2-4 times higher on irrigated land (IAASTD, 2008) However, investment in irrigation technology can lead to trade-offs between downstream and upstream water uses and currently only about 4% of agriculture in Sub-Saharan Africa are irrigated.

Also the application of machinery is seen as bottleneck in the development of agricultural production. For example, the advice of the FAO is to use about 1.5

horsepowers/ha, while in Nigeria only 0.03 horsepowers/ha is used. Overall in Sub-Saharan Africa only 1% of the land is worked mechanically and about 10% is worked with animal draught. (IAC, 2004)

The use of improved genetic varieties of as well crops as livestock is also limited. For crops the use of improved varieties in Africa is limited to about 40% for rice, 17% for maize, 26% for sorghum and 18% for cassava. (IAC, 2004)

3 Possible improvements

3.1 Overview

Land use and degradation are priority issues for the improvement of agriculture in Sub-Saharan Africa. One fifth of land in developing countries is affected by soil erosion or nutrient loss. Improved land management that develops an integrated soil fertility management and water conservation. Possible measures include conservation tillage, stone bounds, water harvesting, use of compost manure, surface mulch, enriched fallows, agro-forestry (see also Box 1), intercropping with legumes, crop residue management or land reclamation can lead to improvements. However, these improvements take a long time and uncertain benefits often prevent investment.

Besides, land that is already degraded and or marginal can be used for the production of crops that can tolerate such conditions. Energy crops are an important example in this category as short rotation wood and high-yielding grasses have typically low nutrient and water requirement. Another often discussed example is the shrub jatropha that produces non-edible oil that could be used for biofuels, see section 3.4.

Pesticides are currently mainly used for crops for the export, while pests and diseases are a major limiting factors in crop yields. Besides increasing the use of pesticides and herbicides also an integrated pest management can contribute significantly to the further development of agriculture. (Bruinsma, 2003)

The improvement of irrigation can possible enhance agricultural management further as only 4% of agriculture is irrigated and water use efficiency could be 3 to 4 times higher. (IAC, 2004)However, irrigation can also lead to trade-offs in water uses and is not feasible in all cases. Other promising technologies for a better water management are the use of small reservoirs, water harvesting, and measures that increase infiltration or reduce runoff.

Genetic variation and breeding of crops and livestock is another major area for the improvement of agricultural efficiency. For this purpose further research should concentrate on genetics and biotechnology. (Bruinsma, 2003) In the end a diversification of agricultural practices is needed, i.e. diversifying products, farming systems and genetic varieties.

While the improvement possibilities vary for different farming systems (Dixon et al, 2001), Bruinsma, 2003 concludes from an analysis of yield gaps, that average yields in Sub-Saharan Africa could for example increase by about 3-5 tonnes grain equivalent per ha in regions where one crop is cultivated each year and by about 3-17 tonnes grain equivalent per ha in regions with 2 to 3 cropping cycles per year. Important factors in such an ‘integrated sustainable intensification’ are the improvement of genetic potentials, water availability, plant nutrition, soil fertility, labour and control of weeds, pests and diseases. Also the reduction of post harvest losses, which amount currently to about 10 to 100%, is a major area for improvements. (IAC, 2004)

Box 1: Tanzania - Sequential and improved fallow in an agroforestry system with maize and rotational woodlots

From 1991 HASHI in Tanzania is cooperating with the World Agroforestry Centre (ICRAF) on the development of appropriate agroforestry technologies for farmers. The purpose of these technologies is to enhance fuelwood and fodder production and to improve soil fertility in Shinyanga in Northern Tanzania. This system consists of crops, trees and livestock and is an intervention to maximize the production of an area of land.

Tree establishment and intercropping phase | Tree fallow phase | Cropping phase | New tree fallow phase

Management phases of rotational woodlots. Source: (Nyadzi et al. 2003).

When agroforestry is focussed on wood production, short rotation woodlots with fast-growing tree species are practised. Rotational woodlot technology involves growing of trees and crops on farms in inter-related phases. Three phases can be distinguished in this system: The tree establishment and intercropping phase, the tree fallow phase and the cropping phase. During the first phase trees and crops are planted. After 2-3 years of tree growth, the tree crown cover starts to block too much sunlight and tree roots compete too much with crops, which causes crop yields to become uneconomical. In this phase the area is left fallow and cattle is allowed to graze. Basically, the woodlot is then managed as a traditional *ngitili*. At the start of the last phase, the trees are harvested and crops are planted in between the tree stumps. Coppice shoots are pruned so that a single new stem is growing. Trees not only have the capacity to provide wood and fodder, they can also function as a natural fertilizer by fixing nitrogen in the soil, which increases crop yields. Yields can thus be maximized by using 'smart' combinations of trees and crops.

Configuration of the seven strata of the rotational woodlot during two subsequent rotation periods, compared to the baseline situation

Source: Adapted from Wiskerke, 2008

A major institutional prerequisite of the development of agriculture in Sub-Saharan Africa is the development of infrastructure and markets. Such a development could enhance the development agricultural technology and help in improvements in crop management and varieties. However, for farming systems with a low potential, the development of markets could be disadvantageous as the have to face growing competition from imports (Dixon et al. 2001).

3.2 Animal production

The production of animal products, i.e. meat, milk and eggs, has a major influence on overall land-use, use of crop residues and the possibilities to produce biomass for energy uses. Concerning overall biomass potentials, using landless animal systems in combination with an increased agricultural productivity could increase biomass potentials in Sub-Saharan Africa theoretically by 7 times compared to mixed animal production systems and modest improvements in animal production (Smeets et al., 2007).

Box 2: Ethiopia - The Begite cow, sustainable fodder production, zero grazing, and investments in goats

This project in Ethiopia has helped to increase the number of varieties of farm animals, which in turn has played a significant role in household asset building, according to the case study.

The Begite cow, a productive breed of dairy cow, has been brought from the western part of the Tigray region, 250 km away from the study area in Ethiopia, which can be seen as an example of technology transfer. The cow gives 6 liters of milk per day compared to the local cow which produces 1.5 liters of milk per day. The cow has demonstrated its ability to survive under harsh conditions like the local cows, and can therefore be important for the economy and food security under the observed climate variability and changes.

The introduction of new poultry breeds and small ruminants are especially targeted at women. A specific loan system for household asset creation, particularly for women-headed households, has been developed. Women take loans from the project to buy 2-4 sheep or goats, which thereafter reproduce five or six times in a few years. This has enabled the women to sell animals and get income for school fees, clothes and food. Fodder production is now practiced, and a system is developed for rearing livestock based on "zero grazing" or "cut and carry system", and supplementary feeding, which is part of the rehabilitation of degraded areas. The enclosure of areas facilitates natural regeneration of vegetation cover on degraded communal lands by protecting them from livestock and human intrusion. Grass is then cut in these areas and carried to the animals.

A more resilient type of animal husbandry here seems to be under development, which is less dependent on grazing in communal lands, and at the same time more productive and economic. In this way the animals can improve food security, income and saving opportunities and at the same time increase people's capacity to handle a drought or a flood or other types of challenging climate conditions. Thus food security becomes less affected by climatic shocks and stresses. The case study points out that these improvements in the household economy have made people able to invest in children's education and to further diversify and increase incomes, thus in several ways increase the capacity to adapt to climatic and other types of stresses.

Source: cited from Ulsrud et al (2008)

Currently, livestock productivity is poor in Sub-Saharan Africa (Otte and Chilonda, 2002), see Figure 2. Different production systems for livestock can be distinguished, i.e traditional systems including pastoral, agro-pastoral and mixed systems and non-traditional systems including ranching and dairy farms. In traditional systems productivities are especially low, while in non-traditional systems such as ranching and dairy farms, productivity is higher due to improved nutrition management and health. For example, the weights of cattle in traditional systems is about 245-250 kg/animal, while in non-traditional systems this is about 310-415 kg/animal. Milk production shows an even greater difference with 2100-3900 kg per lactation reached in dairy systems compared to 220-310 in traditional systems. Even though the productivity of commercial enterprises is relatively high, it still lags behind world average with beef production 20 times less and milk production being 40 times less (IAASTD, 2008) For pigs and poultry the situation is comparable.

In general, performance of livestock production is limited due to genetic resources (see also Box 2) and management practice. Important aspects in management are measure to increase the feed conversion efficiency, e.g. by feeding minerals and to control pests and diseases, e.g. by vaccinations. For example, for pigs and poultry increasing the feed efficiency is a crucial element for improvement. Historically, feed conversion improved by 30-50% by as well breeding as by addition of enzymes to the feed. However, In Sub-Saharan Africa efforts in increasing genetic variety such as importing exotic livestock, crossbreeding and selection had only limited success often due to the poor involvement of community stakeholders (IAASTD, 2008).

Globally, most of the historic increase in productivity results from increasing the production in mixed and non-traditional systems and much less in pastoral systems. (Bouwman et al. 2005) In pastoralism, often marginal lands are used for ranging animals which can be highly productive given the limited resources. However, these systems are constricted by preserving areas for wildlife and more flexible management strategies could improve this system. In agro-pastoral system, more flexible ranging strategies that allow for overstocking during the wet season and for destocking in the dry season could lead to a more efficient use of pastures. (IAASTD, 2008) In mixed and landless systems using land that provides tree leaves or leguminous pods for forage (e.g. agroforestry systems or planting of fodder shrubs along boundarie pathways) can increase overall productivity.

For example, the *fodder bank technology* involves growing high value trees and/or shrubs (*Leucaena pallida, L. diversifolia, Acacia angustissima* and *Gliricidia sepium*) to provide fodder to alleviate shortages of fodder in dry season and consequently, increase and sustain milk production in rural, peri-urban and urban areas. For example, fodder production of up to 6.9 t DM/ha/yr in Tabora in Tanzania has been recorded. Dairy cows on a diet of hay and crop residues yielded 8-12 litres/cow/day when supplemented with dry tree leaves. Apart from fodder, leftovers are used as fuel for cooking and provision of heat in the household.

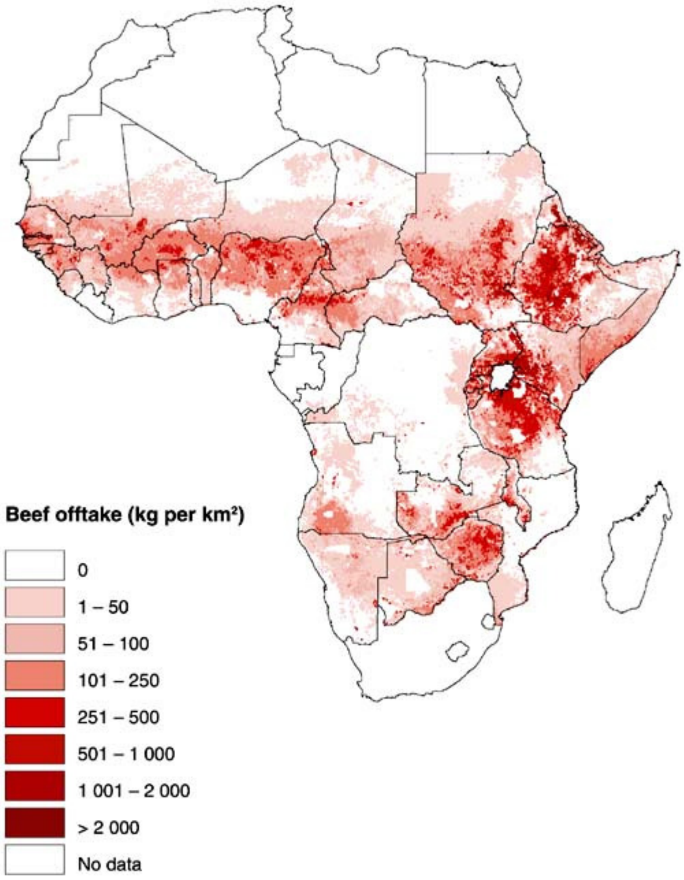

Figure 2: Beef-off take per km^2 in different regions of Sub-Saharan Africa
(Source: Otte and Chilonda, 2002)

3.3 Starch and sugar crops

3.3.1 Sugar cane

Sugarcane is a deep-rooted crop which requires a great amount of water and is extremely sensitive to soil water deficits, exerting a negative impact on wetlands (through direct drainage of wetlands and indirectly through high levels of water abstraction for irrigation). However, the efficiency of water use in terms of biomass production is better than that of many other crops (Woods et al, 2007).

In the agricultural phase, good sugar cane yield and a high index of TRS (total recoverable sugar) are the main drivers for high yield of ethanol per unit of planted area. For example, in Brazil the increase of TRS from sugarcane has been very significant: 1.5% per year in the period 1977–2004, resulting in an increase from 95 to 140 kg/ha. Sugar extraction from sugar cane has also increased in the period 1977–2003 (Goldemberg, 2008).

In Southern Africa as a whole, it is estimated that a 50% increase in the region's 2000 sugarcane production, would require expansion of 200 000 ha of land and create 100 000 jobs. Using GIS, it was discovered that large areas of land are available and suitable for sugar cane cultivation, especially in Mozambique, Malawi and Zambia. The analysis suggests that 'land' is unlikely to be a limiting factor in harnessing sugarcane's bioenergy potential (Watson, 2007). Indeed, between the three mentioned countries, it was estimated that more than 3,700,000 ha were available for sugar cane expansion. However, in some countries water use can be a limiting factor unless drought-tolerant varieties are introduced.

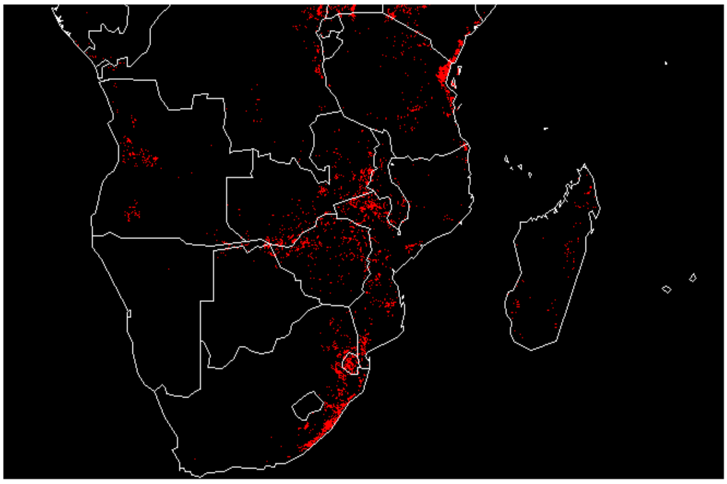

Figure 3: Category of 1 km^2 data delineating in Southern Africa delineating areas suitable for sugarcane & sweet sorghum (Sibanda, D, 2008).

3.3.2 Cassava

Cassava (*Manihot esculenta* Crantz) is a perennial plant of the Euphorbiaceae family and represents the third most important source of calories in the tropics, after rice and maize. It is grown by poor farmers, many of them women, often on marginal land. For those people and their families, cassava is vital for both food security and income generation.

This starchy root crop is grown almost entirely in the lowlands of the equatorial belt between 30° N and 30° S of latitude with an annual rainfall comprised between 200 and 2000 mm.

In the last decades far less research and development have been devoted to cassava than to rice, maize and wheat. This lack of scientific interest has contributed to highly uneven cultivation and processing methods, and cassava products that often are of poor quality.
In the year 2000 FAO launched the "The Global Cassava Development Strategy"; in the framework of this initiative a forum was organized with 80 agricultural experts from 22 countries, who were asked whether cassava had the potential not only to meet the food security needs of the estimated 500 million

farmers who grow it, but to provide a key to rural industrial development and higher incomes for producers, processors and traders. The forum's conclusion were that cassava could become the raw material base for an array of processed products that will effectively increase demand for cassava and contribute to agricultural transformation and economic growth in developing countries. (FAO, 2008)

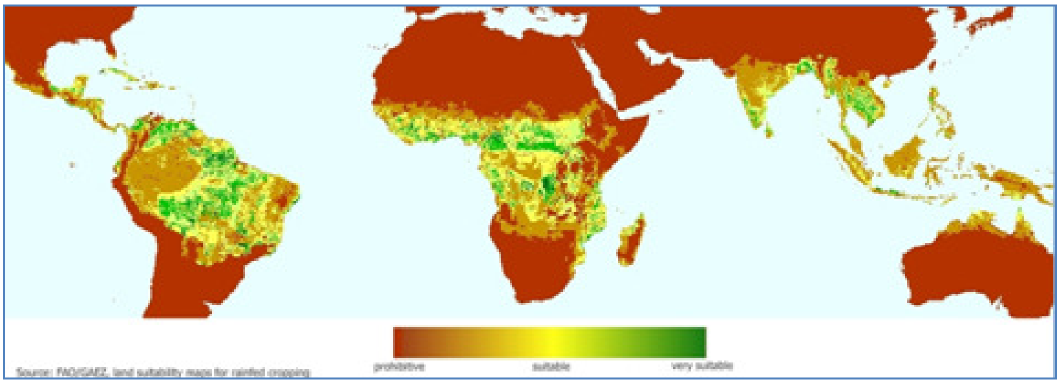

Figure 4: Land suitability map for rainfed cassava. (Source: FAO)

Cassava is an important staple food for millions of poor people in the tropics. Fresh peeled cassava is eaten as a vegetable after boiling or roasting, but peeled roots are often sliced, dried and ground into flour and other several processed products. The main form in which cassava is eaten in West Africa is a roasted granular product, prepared from peeled, grated and fermented cassava roots, known as gari. Kokonte in Ghana is similar to cassava flour except that dried roots are not ground immediately after drying. Chickwangue is prepared by soaking cassava in water for 2-7 days until the roots soften so that they can be peeled and masched, obtaining a paste. Cassava fresh roots contain 30-40% dry matter, up to 30% starch and significant amounts of vitamin C but are poor in proteins.

Moreover, Cassava chips and pellets (also containing leaves) can be used as animal feed; fresh roots are peeled, sliced and sundried on large concrete surfaces. This use is particularly developed in South East Asia (Thailand, Malaysia, Indonesia). Cassava represents also an important raw material for no food industrial uses, i.e. for the production of adhesives, starch, dextrins or also industrial ethanol for chemistry and transport fuel.

Table 5: Main Cassava producers (Source: FAOSTAT, 2008)

Countries	Million tonnes (average 2005-2007)
Nigeria	44.4
Brazil	26.6
Thailand	22.0
Indonesia	19.6
Congo, Democratic Republic of	15.0
Ghana	9.6
Angola	8.7
Viet Nam	7.7
Mozambique	7.1
India	7.0
Tanzania, United Republic of	6.7
Uganda	5.0
Paraguay	4.9
China	4.2
Benin	2.6
Madagascar	2.6
Malawi	2.1
Côte d'Ivoire	2.1
Cameroon	2.1

Finally, cassava flour is receiving considerable attention as a substitute of wheat flour for bread baking. Technologies exist for the use of cassava as a partial substitution for wheat in bread making with unfermented cassava flour (HQCF). In the case of bread, a maximum substitution level of 15% is recommended, depending on the type of bread.

Worldwide Cassava is planted on about 16 million hectares, with 50 percent in Africa, 30 percent in Asia, and 20 percent in Latin America. Total root production is around 152 million tons. It is usually grown in poor soils and harsh climates and in association with other crops, such as maize, beans, or cowpeas. Under these conditions average yields in tons of fresh roots per hectare are quite poor if compared with the potential yields that have been reported from various researches under experimental conditions (up to 90 tons/ha of fresh roots): 9.6 tons worldwide; 7.7 tons in Africa; 12.7 in Latin America; and 12.9 in Asia.

Despite the lack of research and the scarce diffusion of improved varieties and modern cultivation techniques, especially in Africa, were Cassava essentially remains a staple food and has not yet developed into a cash crop (see also Box 3), this species offers several major advantages:

- It is tolerant to poor soils and seasonal drought and has an ability to recover from damage by pests and diseases.
- It can be safely left in the ground for 7 months to 2 years after planting and then harvested as needed.
- Once harvested, though, cassava roots spoil quickly and must be processed within 3 to 7 days to preserve their food value. Nevertheless, after a simple treatment such as sun drying (especially used for cassava chips) the feedstock can be stored for months.
- Consisting of 30 to 40 percent dry matter, the roots contains mostly carbohydrates, but it is also rich in vitamin C, carotenes, calcium, and potassium, though poor in protein. Cassava leaves, in contrast, contain high levels of protein, in addition to being rich in vitamins. In some parts of the world the leaves are consumed as a vegetable or fodder for animals.
- In Asia and Latin America, the roots also provide raw material for small-and large-scale processing into livestock feed and starch. The starch is used in a wide variety of products, including paper, textiles, pharmaceuticals, and various foods, such as crackers, flavoring agents, noodles, and cheese breads. In several countries especially in Asia though still cultivated by small farmers in the most marginal environments of these regions, cassava is rapidly being transformed from a traditional staple into a market-oriented commodity; in Southeast Asia, much of the harvest is already being sold for industrial purposes through domestic and export markets, and Latin America is moving in that direction as well.

Box 3: A successful example: the development of cassava production in the Democratic Republic of Benin

Started in 2001, the Roots and Tuber Development Program (www.pdrt.info) of the Democratic Republic of Benin, is a common initiative supported by IFAD, the local Government and BOAD (West African Development Bank) to help reduce the dependency of the national economy from cotton as the main cash crop, and to improve food security of the part of population that lives in the rural areas of Benin. The program was developed in a broader context of activities for the promotion of diversification of agricultural products. The target groups of this program were farmers and small retailers of fresh and processed cassava products, especially women and young people. Concretely, the aims of the project were the following:

- Improvement of small R&T producers output through the adoption of durable and environmentally friendly practices: use of improved and resistant varieties, integrated fight against destructive pests and improvement of soil fertility;
- Elimination of main constraints weighing on production by boosting the activities of local processor women groups and by encouraging them to unite with other village women groups in order to create marketing organizations;
- Reinforcement of locally-available means to assess and solve problems encountered in R&T development.

During the period of activity of the project (which has ended on June 2008) the following results were achieved:

Research and development

- Development of four improved and efficient varieties of cassava specific for Benin;
- Development of best practice methods for fertilization and rotation with leguminous crops
- Development of cassava based animal feed

Production of improved cassava seeds

- Establishment of a pre-base cutting propagation plantation (332 000 shoots on 14 ha plantation)
- Production of 3,072,000 shoots of pre-base cutting for delivery to breeder peasants on an area 128 ha-wide
- Production of 28,416,000 shoots of certified pre-base cutting on an area 762 ha-wide

The improved varieties were adopted by more than 80% of the supervised producers (more than 11.000 farmers) and the modern agricultural techniques were adopted by 30% of them.

Training and dissemination activities on improved processing techniques

- Training of 6.000 women in improved techniques for making cassava-based gari, tapioca, starch, pulp, lafun, flour suitable for making bread and related products;
- Training for the use of processing equipment and building of traditional ovens;
- Training to bakeries for use of cassava flour for bread production.

Marketing

- Support to the establishment of 15 inter-village marketing associations (AIVC), with the tasks of primary collection, stocking and reselling of products sold by processor women groups (GT).
- Developing a national directory of traders of cassava-based products in order to facilitate business contacts between these and AIVC.
- Collect and broadcast the product prices applied in the 64 markets.

Summary

The successful implementation of this integrated program led to a significant increase of unitary yield, from 10.71 tons/ha in 2001 to 14.53 tons/ha in 2005, (+36%). In some regions, the unitary yield is already above 20 tons/ha. In the same period the national production of cassava has passed from 2.112.965 tons in 2000(on a harvested area of 202.117 ha) to the highest peak of 3.154.910 tons (on an area of 240.073 Ha) in 2003. Thanks to these improvements, Benin is today the 15^{th} largest producer of cassava in the world, despite its small territory compared to the largest producers such as Nigeria or Brazil (see table above). This also gave the opportunity to the country to export its cassava products to neighbor countries especially in the Sahel region (Burkina, Niger, Senegal), but also Congo and Gabon.

Source: M. Cocchi, ETA

3.3.3 Sweet Sorghum

Sugar cane (*Saccharum spp*) and sorghum (*Sorghum bicolor*) are are C_4 plants which have high photosynthetic potential and produce high biomass and sugar content compared to other starch and sugar bearing crops (2). Sweet sorghum has, however, an added advantage over sugar cane. Sweet sorghum has shorter growth period of 3 – 5 months compared to about 18 months for sugar cane. Two crops could therefore be produced per year where irrigation is provided. Sugar cane is propagated from cuttings, requiring 4,500 – 6000 kg/ha of cane, sweet sorghum, on the other hand, is propagated from seed, requiring a minimum of 4 – 7.5 kg /ha of seed. Fertilizer requirement for sweet sorghum is less than half that required by sugarcane. The quantity of water needed by sweet sorghum is only one third of that needed by sugarcane. The crop has high water use efficiency and is drought tolerant. While it is sensitive to low temperatures, it can withstand temperature fluctuations better than sugar cane. Sweet sorghum tolerates some degree of alkalinity and poor drainage and thus can successfully be grown on a wide range of soils. In addition, small scale growers in Zambia are familiar with sweet sorghum which they have been growing in time immemorial.

The potential for sweet sorghum production was evaluated by the Department of Crop Science of the School of Agricultural Sciences of the University of Zambia in collaboration with Zambia Agricultural Research Institute (ZARI), School of Engineering of the University of Zambia, Centre for Energy, Environment and Engineering (CEEEZ) and National Institute for Scientific and Industrial Research (NISIR) from 2004.

The results of the experiments showed that stem yields of sweet sorghum obtained varied with time of planting, plant population, production practices, sweet sorghum variety, level of fertilizer applied, control of pests and diseases and alternative cropping systems.

The *optimum date of planting* was determined from the first experiment. The harvest date varied from 123 Days after planting (DAP) for earlier maturing varieties like Sima to 150 DAP for the later maturing variety like Wray as illustrated in Table 6.

The *required plant population* in sweet sorghum production was determined from varieties representing low (GE2, and Madhura) and high (TS1 and Praj-1) harvest index, see Fig. Stem yields of GE2, TS1 and Madhura decreased with wider intra-row spacing with higher yield obtained between 10 and 15 cm corresponding to a plant population of 133,333 and 66,666 respectively . The highest yield of 22.91 t/ha, 28.33 t/ha and 29.17 t/ha with GE2, TS1 and Madhura respectively was obtained at a narrower spacing of 10 cm. Praj-1 was an exception where the stem yield increased with wider spacing and the highest yield of 40.74 t/ha was obtained at the widest intra-row spacing of 25 cm. Sweet sorghum plants were tallest (2.29 m) at the narrower intra-row spacing of 10 cm followed by an average of 2.17 m at 15 to 20 cm and least of all (2.1 m) at 25 cm.

Table 6: Optimum date of planting of sweet sorghum varieties

Variety	Optimum date of harvest (Mean)	Class	Maturity
Sima	124	1	Early
Praj 1	125	1	Early
GE2	126	1	Early
Cowley	127	1	Early
Madhura	127	1	Early
TS1	128	2	Medium
GE3	132	2	Medium
Keller	133	2	Medium
Wray	134	2	Medium

Disease incidence was greater with taller plants associated with higher stem yields at narrower spacing and minimum at a wider spacing. This is supported by strong correlation of Anthracnose disease prevalence with plant height and stem yield across sweet sorghum varieties.

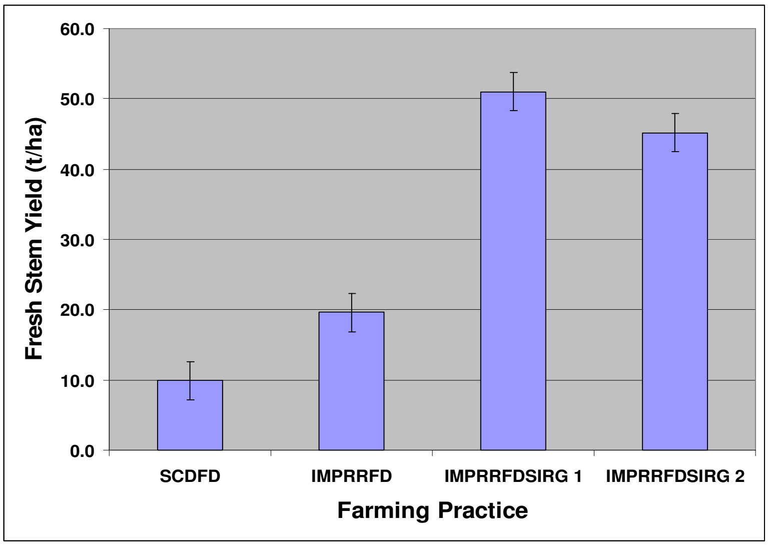

Figure 5: Variation of stem yield with farming practice

Sweet sorghum stem yields varied significantly with *production practice*, see Figure 5. Yields were highest in the first crop under improved rainfed with optimal fertilizer application and under supplementary irrigated conditions (IMPRRFDSIG 1). This was followed in the second crop of same farming practice (IMPRRFDSIG 2) and then improved rainfed with optimal fertilizer application (IMPRRFD). The yields were lowest under rainfed and suboptimal fertilizer application. (SCRFD) The yield increase over SCRFD was 413.3%, 355.2% and 97.6% with these systems respectively.

Yields of *Sweet sorghum varieties* varied within and among the farming practices as depicted in Figure 6 below. Under IMPRRFDSIG1 highest stem yields were obtained with GE3 followed by Cowlley, Wray, TS1 and Praj-1 with a yield of 85.38, 73.68, 66.30, 52.66 and 42.66 respectively. Under double cropping a sum of the stem yields of crop 1 and crop 2, highest and similar yields were obtained with Wray and GE3 with an average of 134.6 t/ha an increase of 154.8% over the control. This was followed by TS1 (121.6 t/ha) and similar yield of Cowlley and Praj-1 with an average of 99.92 t/ha. The yield increase over with TS1 over the control over the control was 130.1% while it was 89.1% for Cowlley and Praj-1.

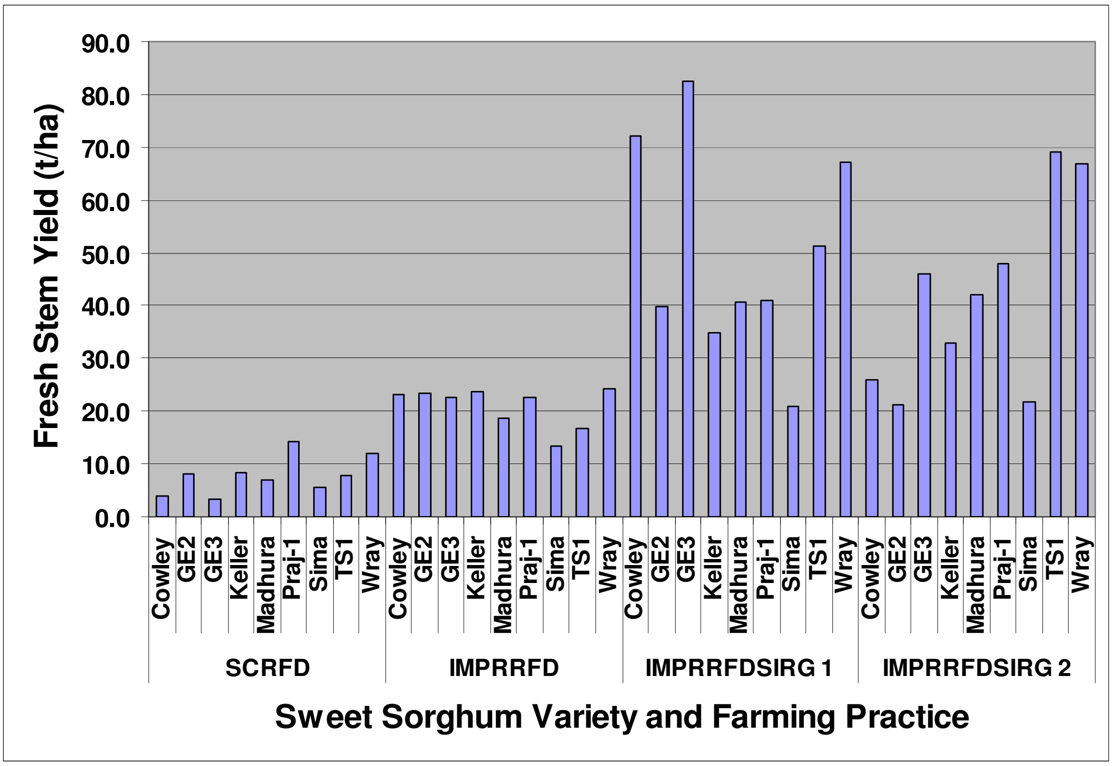

Figure 6: Variation of sweet sorghum stem yields within and among farming practices

Under improved rainfed conditions with optimal fertilizer application, fresh stem yields averaged across sites were highest with Wray, Praj-1, Keller, Cowley and GE2. The lowest yield of 13.8 t/ha was obtained with local sweet sorghum variety Sima. The lowest yields of sweet sorghum varieties were obtained under small-scale suboptimal fertilizer application. Under this practice the highest yield of 16.31 t/ha was obtained with Praj-1. This was followed with Wray with 13.26 t/ha. The rest of the varieties were similar in yield with Sima with an average yield of 9.03 t/ha.

The yield of sweet sorghum averaged across varieties was highest at Mulapezi on more fertile soils of phaeozems with an average yield of 32.4 t/ha. Stem yields were as high as 50 t/ha with GE2 and Praj-1 on this soil type. The lowest yield of 9.7 t/ha was obtained on Ferralsols.

Stem yields of sweet sorghum varied with *level of fertilizer* applied. Across varieties and soils lower stem yields were obtained with suboptimal fertilizer application. There was a yield increase of 97.6% with optimal compared with suboptimal fertilizer application. Stem yields of sweet sorghum variety Sima were higher under rainfed conditions when fertilizer was applied at the highest level of 120 kg N/ha and 120 kg P_2O_5/ha. There was a highly significant effect of N on stem yield. Highest stem yields of 14.74 t/ha, followed by 14.49 t/ha and 13.56 t/ha were obtained at 120 kg N/ha with inoculum and without inoculum and at 60 kg N/ha respectively. This represented an increase over the control of 193.3%, 183.5% and 165.3% respectively. The effect of P on stem yield was much less. It was only recorded at the highest rate of 120 kg P_2O_5/ha with a yield of 13.19 t/ha an increase of only 11% over the control. Inoculum on its own did not increase productivity. Its effect was to enhance the effect of N and P at the highest rate of 120 N kg/ha and 120 kg P_20_5/ha where there was an increase in stem yield of 0.505 and 1.085 kg/ha over the uninoculated treatment. Generally, yields of Sima were 58.9% to 77.0% higher under rainfed with N and P applied at 120 kg/ha compared to sub optimal fertilization application.

Damage of sweet sorghum plants were mainly caused by stem borers as indicated by the negative and strong correlation of stem borers and damaged plants. Most of the reduction in stem juice was from stem borer feeding. Botanical *pesticides* Neem and Tephrosia were as effective in reducing the number of holes (entry points into the stem) as conventional pesticides Phorate and Monocrotophos, Figure 7. Least control was observed in the control and Carbofuran treatments. Neem and phorate were the two most effective treatments in reducing the number of stem bores. While there were more stem bores on plants treated with Tephrosia and Monocrotophos these did not gain entry into the plant as opposed to the control and Carbofuran where they did. This is supported by reduced tunnel length especially in Neem, Monocrotophos and Tephrosia.

Summarizing, management practices can significantly influence the yield of sweet sorghum. The yield still increases further under rainfed and optimal fertilizer conditions but with supplementary irrigation. The combination of taller plants and higher stem yields could have both created conditions (probably higher relative humidity) more favourable for the development of anthracnose.

Although highest yield were obtained at narrow spacing this was, however, associated with significantly higher athracnose disease prevalence and greater lodging of plants compared to a wider spacing. Production of sweet sorghum at narrower spacing would increase the cost of production from applying fungicides. Therefore, sweet sorghum production should be grown at an intra-row spacing of between 15 and 20 cm. Cost of production could be reduced by use of botanical pesticides Neem and Tephrosia vogeli which were as effective as chemical pesticides Carbofuran, Monocrotophos, and Phorate.

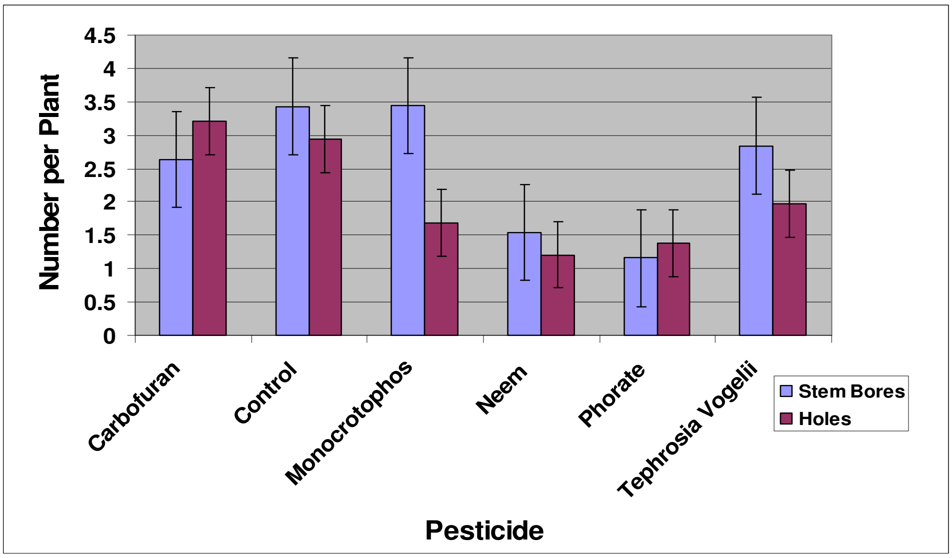

Figure 7: Effect of botanical and conventional insecticides on control of stem bores in sweet sorghum at UNZA Farm in 2007/08 season

Wray, GE3, Praj-1, Cowlley and Keller were found to have highest stem yield and sugar content for sweet sorghum production. Dual purpose sweet sorghums are an attractive option as they provide both food and stems. The competition between food and energy is minimized. Improved varieties of sweet sorghum are very promising as they are able to produce more than 100 t/ha per harvest and have moderate values of Brix% (10.0 to 15.5).

Although Sima Sweet sorghum variety has lower stem yields, production should start with use of Sima because the seed is available. It is therefore recommended to identify and develop appropriate sweet sorghum varieties and cropping systems for sweet sorghum production.

3.4 Oilseed crops

3.4.1 Palm oil

The Oil Palm (*Elaeis guineesis*) originated in West Africa. The plant has a close mat of adventitious roots, with a stem that can grow up to a height of 30m. There are three types of oil palm, DURA, PISIFERA and TENERA. TENERA is a hybrid of the other two varieties; it has more oil content and higher oil yield per unit area than the other two varieties.

Oil Palm is cultivated throughout Equatorial Africa where altitude is below 700m and rainfall is up to 1,700m annually. Oil Palm is planted in the field at a spacing of 9m x 9m i.e. 125 plants per ha with potential yield of 18 to 20 tons of fruit bunches per ha per year. In Africa, the yield ranges from 12 to 13 tons of fruit bunches per ha per year.

Palm oil has multiple uses. It can be used for cooking, making soap, cosmetic, lubricant for machines, candles, vitamin tablets, ornamental, shade, demarcation, compost, brooms, carpets, beehives, canoe making. It can also be used as biofuel, i.e. as pure plant oil in adapted diesel engines or after esterification as biodiesel. The comparative oil yield per ha per year that oil palm produces is 10 times higher than oil yields from sunflower and 3 times higher than oil yields from coconut.

Important field operations for the cultivation of palm oil include:
- timely planting (during the on set of the rainy season in the given area),
- proper weeding and pruning
- timely harvesting
- proper and timely processing.

One of the major expenditure in oil palm production is on fertilizers. Use of appropriate fertilizers can increase production up to 51.8% for fresh fruit bunches (FFB), up to 33.8% for red oil and up to 17.7% for kernel oil per ha per year.

Major improvements in palm oil production can be achieved by proper management, i.e planting, weeding, fertilizer application and harvesting. Also breeding of higher yielding varieties and replanting of old plantations with higher yielding palms are crucial to improve yields in many regions, see also Box 4. Finally, extraction of oil preferably with higher yielding non-manual devices and a timely processing can increase yields further.

Table 7: Main management characteristics of palm oil

Parameter	Value
Pre-germination	Takes 2 to 3 months
Nursery period	Takes 9 to 12 months
Planting to first harvesting	Takes 2.5 to 3 years
Period of economic harvest	5 to 30 years (under good management)
Recommended plant population	125 to 150 plants per ha
Expected oil yield per ha	3,500 to 4,500 kg/ha/year
Optimum rainfall	1,500 to 2,000 mm/annum
Optimum temperature	25 to 32 Degrees Centigrade

Box 4: Improvements in smallholder palm oil production in Kingoma region, Tanzania

Kigoma region

Tanzania has 22 regions (provinces) and Kigoma is one of them which has a population of 1.7 million (this is about 5% of Tanzania's population according to 2002 censer). It has a population density of 45 persons/km^2 compared to a national average of 39 persons/km^2. The average household size is 7 persons which is higher than the national average of 4 persons. It has a population growth rate of 4.8% per annum (between 1988 and 2002).

Its mean annual rainfall is above 700mm/annum, and it experiences a dry-spell in June to September, which influences the oil palm growth and has implications for the need to irrigate land to ensure a high yield for the plants. Kigoma has a scanty road network and has only 28 km of paved road. This shows that Kigoma has poor infrastructures and hence poor market access for farmers.

Most of the palm oil in Tanzania is produced in the Kigoma region (90% of the palm) and most or almost all of this oil is produced by smallholder farmers. While in Africa, the yield ranges from 12 to 13 tons of fruit bunches per ha per year, in Kigoma, palm oil yields are around 5 tons of fruit bunches per ha per year. It should be noted here that there is no research centres for oil palm in Tanzania, so farmers use the locally available low yielding varieties of DURA. In addition to this, the palm trees we see today in Kigoma were planted about 30 to 40 years ago and hence have very low yields (less than a ton of oil per ha per year) as they are very old.

Lack of improved planting materials, inadequate extension services, use of fire to weed the fields, lack of farmers organizations to defend their interests, prolonged dry spells, lack of reliable and efficient oil extracting factories and poor feeder roads causing a big problem of transportation; these are some of major problems leading to very poor yields of palm oil in Kigoma.

Oil Palm production in Kigoma is based on small holder farmers. These farmers operate under very high stress conditions as there is no improved seeds or seedlings readily available to them, no reliable market for their oil as government is doing almost nothing to assist them and poor oil extraction methodology. Oil is extracted locally using local extraction mechanism which extracts only 40% of the oil from the fruits. Bearing in mind that the oil palm are of low yielding, very old trees plus poor extraction mechanisms, farmers end up into getting very low oil yields and hence are discouraged for many years.

Improvement strategies:

For the recent years, especially after the involvement of FELISA Co. Ltd and the investment act and free trading in the country, there are some improvement strategies in the region for the production of palm oil and Investors have established the morale of farmers to go for improvement of their farms.

For instance, FELISA has a breading programme where TENERA hybrid is being produced for their plantation and their out growers (the smallholder farmers). Through FELISA farmers get hybrid seedlings at affordable price. There are also some NGOs such as TOCDA (Tanzania Oil Crop Development Authority) which are also breed (crossing) palms to get hybrid seeds for farmers.

Through the FELISA out grower scheme, farmers now weed their small plots instead of using fire, they are getting improved seedlings (hybrid seedlings) for instance for the past two years FELISA donated 10,000 hybrid seedlings to its out grower – given to 200 small holders farmers. This is very encouraging to farmers. In addition FELISA has been buying the fruit bunches from farmers at a better price than those given by the middlemen, this is also encouraged smallholder farmers to take care of their plots instead of using wild fire as a weeding mechanism.

Still, improvement of the palm oil sector will be a long way to go as there is little assistance from the government and hence time will be needed before bioenergy production sounds in the region. This is due to the fact that Government assistance in crop development is donor dependent. Most donors are interested in cash crops such as tea, coffee, sisal etc. If donors would get involvement into crop development of energy crops, they would probably engage in jatropha rather than palm oil.

Source: H. Hongo, Felisa Co Ltd.

3.4.2 Jatropha

Jatropha is a shrub producing seeds with a high oil content that can among other be used for the production of biofuel. Traditionally the seed has been harvested by women and used for medical treatments and local soap production. The oil which can be pressed from its seed is non-edible.

Jatropha is grown around crop fields and gardens to keep out animals, act as a windbreak, and to reduce soil erosion by wind and water. As it can be grown on marginal land and is drought resistant, it could have a major potential for future bioenergy production in semi-arid and arid with limited competition with food crops. At the moment, many commercial and non-commercial projects of jatropha plantations are starting-up. However, because of high yields, many of these projects are implemented on land with a relative good quality outside of semi-arid and arid areas.

Jatropha needs only 400mm annual rainfall to grow, which means it can flourish even in Sahelian and semi-desert regions. In general, an annual rainfall of 400 to 2500 mm is suitable, while the mean annual temperature should be between 18 and 23 °C. In Tanzania, Jatropha also does well in areas where the rainfall is only 250 mm, but the humidity of the air is very high. Jatropha is fast growing plant that takes about 2 years to produce seed if grown from seed and about 1 year if grown from cuttings.

When Jatropha is planted in hedges, the wind blows soil to accumulate at the base of the plants, forming boundaries along the ground. This holds in water, allowing more absorption of water into the soil and consequently less loss of soil carried away by surface runoff. The roots of the plants also break up the earth which can become compacted during the dry season, causing high surface runoff when the rains come. This again allows more infiltration of water into the soil. It, therefore, can contribute in the combat against desertification.

The production of good quality fertiliser as a by-product of oil production will also act to improve soils and agricultural production (small scale gardening). 1 hectare of Jatropha is estimated as giving 3 tonnes/hectare per year when plants are mature. This gives around 0.75 tonnes of oil and 2.25 tonnes of presscake which can be used to produce high quality organic fertiliser. The presscake fertiliser is significantly richer in nitrogen and phosphates than cow dung, while contents of potassium and calcium are lower. While Jatropha press cake contains about 5.7-6.5% of N and 2.6-3.1% of P_2O_5, cow dung contains about 2% and 1.5%, respectively (GTZ, 1995).

Furthermore, jatropha production is low input and requires not tillage (Francis et al., 2005). The groing of Jatropha is also associated with improved livelihoods due t employment creation associated with the establishment of nurseries and also because of the restoration of degraded lands known to have a zero opportunity cost (Dufey, 2006; Francis et al., 2005).

Box 5: Jatropha production for rural electrification in the Garalo Bagani Yelen project, Mali

MFC Nyetaa, in collaboration with its partners, has embarked on the implementation of a large scale Jatropha-fuelled rural electrification project in the village of Garalo in the Sikasso region of southern Mali. Based on the long standing request of the population to have access to modern energy, the commune of Garalo is setting up 1.000 ha of Jatropha plantations to provide the oil for a 300 kW power plant that will provide clean electricity for more than 15 years. MFC will organize the project activities and provide technical support. This innovative project will provide electricity and other modern energy services to more than 10.000 people of Garalo commune, transforming the local economy. By providing power for productive use in small industries and businesses, generating employment, and supplying power for social uses in schools, the maternity clinic and community buildings as well as for domestic use.

The project is now in its execution phase. Three generators of 100 kW each have been installed and converted to run on pure Jatropha oil, and a nursery has been created to produce the 1 000 000 Jatropha seedlings needed to plant 1 000 hectares of Jatropha in the municipality. Currently, 115 ha have already been planted. The Mayor of Garalo projected another 900 hectares will be planted over the next three years. This will produce more than enough oil for power production. The project should be a model for genuinely sustainable biofuel projects in the future.


The production of Jatropha does not require irrigation, so there is no increased pressure on the scarce and diminishing water resources. It is grown on a mixture of unused and abandoned land, as well as in people's own fields. But it is not in competition with food supply. Rather it provides an income generating alternative to cotton, which farmers are increasingly dissatisfied with due to the poor returns caused by heavily subsidized international markets and high requirements for pesticide.

Use of Jatropha for rural electrification can:
- be a sustainable solution to the local people's electricity generation needs;
- make people independent of fossil fuels (energy independence);
- help generate income by allowing cheaper electricity production;
- generate additional income for farmers and women's groups through the production of Jatropha seeds.

The possibility to produce CO_2 neutral electricity on such a scale in Mali is a great opportunity. Mali has been hit hard by the effects of climate change, with reduced rainfall, increased risks of drought and associated food security problems. The planting of Jatropha can improve degraded soils, and can increase absorption of water and reduce wind and water erosion of the soil. No pesticides or fertilizer is used. Organic fertilizer is produced as a by product which can additionally improve agricultural production.

Source: I. Togola, Mali-Folkecenter

3.4.3 Other oil crops

There are a large number of potential biofuel oil crops. Many of these crops produce edible oils. For example, cotton is mainly a smallholder's crop and is a main cash crop in many African countries. Apart from being fiber crop, cotton seeds can be squeezed and produce edible oil. For example in Mali, cotton seed oil is the main oil used for human food purposes. However, it could also be used for the production of biodiesel in areas where it is less used. Also non-edible oils like like castor beans are a possible option. Fruits from forest trees can also contain oil that can be used for bioenergy purposes even though many of the fruits are used for human consumption.

Table **9** gives an overview of some forest species that could be used for oil production.

Table 8 shows a range of possible oil crops and their yields in Tanzania. Fruits from forest trees can also contain oil that can be used for bioenergy purposes even though many of the fruits are used for human consumption.

Table 9 gives an overview of some forest species that could be used for oil production.

Table 8: Oil yield per hectare for different crops found in Tanzania (Source: Shuma, 2008)

Crop	Kg oil/ha
Avocado	2217
Cashew nut	148
Castor beans	1188
Coconut	2260
Coffee	386
Cotton	273
Euphorbia	440
Jatropha	1590
Jojoba	1528
Macademia nuts	1887
Maize	145
Mustard seeds	481
Oil palm	5000
Olives	1019
Peanuts	890
Pecan nuts	1505
Pumpkin seeds	449
Rape seeds	1000
Rice	696
Sesame	585
Soya bean	375
Sunflowers	800
Tung-oil tree	790

Table 9: Forest resources for fuel production (Source: Shuma, 2008)

Plant	% oil content	Favorable climatic conditions
Kapok *(Ceiba pentandra)*	25	At the coast and along coastal areas
Eucalyptus *(E. globulus)*	10-85	Loam soils, wet mountain climates, over 2000 m
Pappea *(Pappea capensis)*	?	Drier forests, savannah, open woodlands
Marula *(Sclerocarya caffra)*	60	Low altitudes, woodland, wooded grassland, 100-1600 m, 200-16000 mm rain/year, salt tolerant
Pigeon wood *(T. Guineensis)*	?	Higher rainfall areas, 0-200 m
Cape mahogany *(T. Roka)*	55-65	Well-drained, rich soils & high ground water areas
Margosa seeds *(Azadiracht indica)*	20-45	Pan-tropical in semi-arid and arid regions (withstanding drought). Very dry areas, poor soils, 1-1500 m
Desert data *(Balanites aegyptiaca)*	40-46	From arid and semi-arid regions to sub-humid savannah, 200-800 mm rainfall, 0-2000m
African fan palm *(Borassus aethiopum)*	?	Less dry areas of tropical Africa.

3.5 Ligno-cellulosic energy crops

Ligno-cellulosic crops for energy comprise a broad variety of crops and agricultural and forestry management systems. The first category of crops includes trees and woody crops that can be cultivated either in traditional forestry systems or in agro-forestry systems. Here, we will concentrate on agricultural practices and describe major practices of agro-forestry. The second category of crops is fast growing grasses such as miscanthus and switchgrass.

3.5.1 Agro-forestry in semi arid lands

Agro-forestry systems use a wide variety of management practices and species. They range from afforestation and reforestation with slow growing species, to woodlots for fuelwood production of short rotation (coppice) wood, to systems that combine annual food crops with wood production. Besides the possible use of lingo-cellulose from these systems, they also reduce the pressure on forest resources for the production of timber, fuelwood and other products and have additional benefits on soils and the environment, see

Table 10.

The major goal of many *tree planting programs* was to increase fuelwood production to reduce the rural energy crisis. Village woodlots were therefore emphasized as means of meeting future fuelwood shortages. However, in dry land farming areas growth rates of trees are slow, survival rates are poor and protection of seedlings against fires and animals can be a problem. For example in Tanzania, protecting areas from grazing animals has been found to be much more effective way of restoring the natural vegetation and tree cover under the "Ngitili" system in the Sukuma land.

Another recent purpose of afforestation and reforestation projects is the sequestration of carbon and the generation of carbon credits for the CDM or voluntary carbon markets. However, financing of such projects is often difficult and an important open question is the level of future market price of forest-based carbon. (Murdiyarso and Skutch, 2006)

In community and farm forestry, agro-forestry can form an integral part of natural resource management. Various agro-forestry technologies have been tested for soil improvement, fuelwood and fodder production and have yielded encouraging results. Early community and farm forestry research focused on woodlots and home gardens. However, these systems seemed to work well in humid areas where soil moisture is not a constraint as opposed to semi-arid areas. Rocheleau et al., (1988) documented agroforestry options for the dry lands of Africa. There exist various agroforestry options for the arid and semi-arid areas Alternative agro-forestry technologies for semi-arid areas are *intercropping*, *boundary planting*, *rotational woodlots, improved fallows* and *fodder banks*.

Table 10: Possible benefits of agro-forestry systems

Soil nutrients and organic matter	Other effects soil	Others
Taking up nutrients released by rock weathering in deeper layers and recycling it tot the surface	Improvement of soil physical properties, e.g. structure, porosity, WHC, breaking up of indurated layers	Atmospheric input by trapping rainfall, dust and nutrients
Nitrogen fixation by leguminous and non-leguminous trees	Exudation of growth promoting substances	Wind effects: act as windbreaks and therefore as anti-erosive agents
Production of a range of plant litter of different quality	Beneficial effects on soil flora and fauna	Capture industrial aerosols and therefore purifies air and reduces air pollution
Increases of soil organic matter carbon fixation in photosynthesis and transfer via litter and root decay	Modification of soil temperature extremes	Rehumidify air streams
Prevention of soil erosion and loss of organic matter and nutrients	Reduction of soil acidity through addition of plant litter	Control air temperature by evaporative cooling
	Reduction of salinity or sodicity	Noise reduction

For intercropping of crops with trees many possibilities exist. For example, in Tanzania, some agroforestry trials were established testing the intercropping of cereals with *Leucaena leucocephala*. Others were looking at the production of fodder for stall feeding cattle.

Trees planted on boundaries are often used to demarcate land under communal ownership especially in the Sukuma land. Trees planted on boundaries cut down wind speed, water and soil erosion, and improve soil structure and fertility. In the Sukuma land in Tanzania, for example, people have planted *Euphorbia tirucalli* as live fence for farm protection and as wind breaks as. Others have planted *Senna siamea, Jatropha Curcas*, *Azadrachta indica*, *Albizia lebbeck*, Australian acacias, *Leucaena leucocephala* and have left indigenous trees like *Acacia nilotica* and *Acacia polyacantha* to mention a few on their farm boundaries.

The idea of *rotational woodlots* is that trees are planted together with food crops for the first three years and when it is not economical to plant crops under the tree canopy trees are left to grow for other two to three years before they can be harvested for fuel and construction. Farmers, however, have left their trees longer than the predicted rotation age of five years, and some left their trees up to more than ten years. Fast growing Australian acacias have yielded 40 – 90 tons per ha of dry wood in only five years. Rotational woodlots have great potential in rehabilitation of degraded lands in the country. Species used are among others: Australian acacias, *Senna siamea, Acacia nilotica*, *Acacia polyacantha*, *Brachystegia spiciformis*, *Teminalia sericea, Pterocarpus angolensis, Afzelia quanzensis*, *Melia azedrach*, *Casuarina junghuhniana* and *Cedrela odorata.* Wood can be used to supply both fuelwood and timber.

Box 6: Sustainable and Participatory Energy Management Project, Senegal – Woodfuels Supply Management

The set-up

The Sustainable and Participatory Energy Management project - PROGEDE (IDA $5.2 million; DGIS $8.8 million; GEF $4.7 million) was implemented by the Government of Senegal between 1997 and 2004. From project preparation to supervision the World Bank worked in close collaboration with the Dutch Co-operation (DGIS). At the time of project preparation, forest-based traditional fuels (firewood and charcoal), mainly used for household cooking purposes, represented 53% of Senegal's final energy consumption. The bulk of the consumption of charcoal (76%) took place in the principal urban areas. Over the years, the operation of the charcoal industry in Senegal had resulted in (i) the gradual loss of forest cover (approximately 30,000 ha per year) and thus of the ecosystem's carbon sequestration capacity and biodiversity; (ii) the degradation of the rural environment (particularly soils); (iii) the impoverishment of the rural areas; (iv) an acceleration of rural exodus; and (v) a massive transfer of wealth from the rural communities to a few urban-based woodfuel traders. These negative impacts disproportionately affected the rural women and children.

The project focused on (i) supply side management through the implementation and monitoring of *300,000+ hectares of environmentally sustainable community-managed forest resource systems* in the Tambacounda and Kolda regions, forming in the process a managed protection zone around the Niokolo-Koba National Park ("International Bioshepre Reserve"); (ii) demand side management activities in the form of promoting private sector inter-fuel substitution and private sector and NGO-based improved stoves initiative; and (iii) capacity development activities to strengthen the institutions involved in the management of the sector, and the promotion of the participation of civil society in the operation of the sector, with a special focus on gender development and mobilization opportunities at the village and regional levels.

Main impacts on the ground

Beyond its energy objectives and targets, the project is credited with having generated a significant and quantifiable rural poverty alleviation impact within a socially and environmentally sustainable framework, and with a particular positive impact in terms of gender development and welfare (new employment and incomes and training on organizational and management skills, on economic diversification, health and nutrition).

Sustainable Woodfuel Supply

The Sustainable Woodfuels Supply Management Component of the project directly benefited some 250,000 people – equivalent to approximately 21% of the population in the Tambacounda and Kolda regions – and an estimated 100,000 urban charcoal-consuming families. This component achieved the following outcomes and outputs:

- Sustainable community-managed forest systems were established over an area of 378,161 ha, with a supplying capacity of more than 370, 596 tons per year of sustainable fuelwood, equivalent to some 67,400 tons of charcoal per year.

- A community-managed buffer zone was created around the Niokolo-Koba National Park.
- Participating rural communities and NGOs implemented participatory natural resource management modules and produced and marketed woodfuels and multiple other non-wood products, with a strong gender participation;
- Community-base micro enterprises were established including beneficiary-operated improved carbonization units, apiculture cooperatives, collective and individual agricultural diversification units/systems; livestock and poultry-raising, arts and crafts units, etc. While woodfuel and large livestock activities where mostly led by men, all other activities where generally managed and operated directly by women (groups and individually);
- The establishment of a *sustainable incremental* income generation base (wood and non-wood products) of about *$12.5 million per year*, equivalent to a $40,000 average per participating village. This corresponded to 418% achievement with respect to the Appraisal target. Of that total more than *US $3.7 million (30%) resulted from women-led economic activities*; and,
- More than 20% of Senegal's current energy supplies are now derived effectively from renewable resources in the form of sustainable woodfuels.

Lessons learned

The project demonstrated that the production and marketing of traditional biomass fuels can not only be stabilized, while arresting deforestation and contributing to ecological conservation, but that it can become a highly effective social and economic rural development strategy, with significant and measurable gender development impacts.

The stabilization of the traditional energy sector essentially depends on the implementation of comprehensive changes in the woodfuels' supply system and chains. While demand management are important and need to be pursued – especially dissemination of improved end-use technologies and practices – that alone cannot resolve the existing problems;

The establishment of environmentally and socially sustainable woodfuel supply systems can only be achieved through the introduction of integrated community-based and gender-balanced forestry and natural resources management schemes. Governments lack the financial resources, the manpower and the incentive to do this; the private sector is not interested because of the long payback period, inherent risks and low profit margins;

Source: Senegal PROGEDE - Traditional Biomass Energy and Poverty Alleviation, Implementation Completion Report No. 32102.

Soil fertility can be major constraint for agricultural production in semi-arid and arid areas. *Improved fallows* technology has been introduced to increase soil productivity. Tree and herbaceous legume species being promoted, for example, in the semi-arid areas of Tanzania include *Sesbania sesban, Gliricidia sepium, Acacia angustissima, Tephrosia volgelli, Cajanus cajan* and pigeon pea.

3.5.2 Fast growing grasses

Fast growing grasses (e.g. miscanthus and switchgrass) are seen as an important alternative to produce lingo-cellulosic feedstock for bioenergy production. In the conditions of semi-arid and arid Sub-Saharan Africa such a production seems feasible; however, as far as known no experiments with fast growing grass production for bioenergy have been carried out so far.

In West Africa countries launched an African Miscanthus Plantations project that should start with the establishment of a plantation of 200 hectares in Benin. It is envisaged that further plantations in West Africa will follow in the next 15 years. It is expected that 200 ha of plantation will result in an investment of €800,000 and a predicted rate of return of 20 to 30%, and about 30 direct and 100 indirect jobs. Furthermore, yields of up to 30 $tons_{dm}$/ha/yr expected (Biopact, 2009)

4 Summary

Agricultural production in Sub-Saharan Africa has on average a low efficiency compared to other parts of the world. This is valid for crop production for food as well as for bioenergy purposes and for livestock production. Increases in agricultural efficiency could on the one hand make resources such as labour and land available for increased bioenergy production and on the other hand improve the production of bioenergy itself in terms of production costs and efficiency of crop production.

In general, agricultural efficiency could be increased by increasing inputs such as fertilizers, labor and mechanization and by applying best practice agricultural management systems. Moreover, mixed cropping systems and multiple production (e.g. crops for food, livestock and bioenergy crops) can often be a good strategy for improved land use systems. However, it should be noted that conditions in semi-arid and arid Sub-Saharan Africa can vary widely in terms of climate, predominant farming systems and cultural heritage. Therefore, improved land use systems will have to be evaluated in the context of these settings.

From the COMPETE network interesting examples for improved land use strategy that relate directly to bioenergy production emerged such as:

- Agro-forestry systems to produce woodfuels (e.g. woodlots and intercropping of wood with food crops)
- Jatropha plantation for the use of pure plant oil or biodiesel in various diesel engines
- Improvement of small-holder production of palm oil for the use in food and biodiesel applications
- Improvement of cassava and sweet sorghum by defining optimal management strategies and breeding programs and the use of cassava and sweet sorghum for ethanol production.
- The use of fodder banks and the possible cultivation of grasses for energy purposes

On the basis of these experiences, possible improved land use options in combination with improved bioenergy options will be further regarded, possible projects will be proposed and the overall impacts of improved land use in arid and semi-arid Sub-Saharan Africa will be estimated.

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